TELECOMMUNICATIONS AND MISSION OPERATIONS DIRECTORATE (TMOD)

SERVICES CATALOG

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TABLE OF CONTENTS

1. Purpose of the Document

The Telecommunications and Mission Operations Directorate (TMOD) at JPL supports flight projects and science investigations through its service system, i.e. the Deep Space Mission System (DSMS). The DSMS is a consolidated system of the two JPL multi-mission systems, i.e. the Advanced Multi-Mission Operations System (AMMOS) and Deep Space Network (DSN), plus the on-board data system. In general, TMOD support to its customers can be categorized into 3 types: (1) mission operations *services*, (2) *tools* used by customers to operate their missions and to develop their mission operations system (MOS), and (3) other *engineering support* such as those activities performed to support project mission design, telecommunication link analysis, end-to-end integration and test, etc. In the past, distinctions between these 3 types of support were rather vague. As NASA moves into an era of full cost accounting, there is an urgent need for TMOD to be the service provider to all deep space missions. A clear definition of services and other two types of support is thus needed to delineate mission-specific capabilities (which must be developed or adapted by each flight project) and the multi-mission services (which can be more readily available to any flight project) so that not only the most cost effective approach to building a project MOS is possible but also the best performance and cost accountability of service provision can be accomplished.

The TMOD Services Catalog defines standard mission operations services available to customers of TMOD. Although many of the services defined here are applicable to both deep space, Earth orbiting missions, and other mission domains, in the context of NASA integrated space operations system under the management of the Space Operations Management Offices (SOMO), this service catalog in contents is a subset of the SOMO Services Catalog and is intended mainly for deep space mission and high Earth orbit mission customers. Its specific usage can be summarized as follows:

(a) It provides a standard taxonomy of TMOD services as a basis for all customers to request support in areas of telecommunications and mission operations from TMOD. This approach differs significantly from the way TMOD support was offered in the past, i.e. the provision of DSN assets (such as antennas) and AMMOS tools as the primary commodities to customers. The service definition is therefore an important input to the development of a Project Service Level Agreement (PSLA) and Project Commitment Document (PCD).

(b) It provides service pricing information for pre-project customers to derive life cycle cost estimates for their mission operations systems. This is crucial in an era of full cost accounting as the mission selection process conducted by the various NASA Enterprises must take into account the expenditure on multi-mission support.

The Services Catalog is not a requirements or design document, nor is it a interface specification. For purpose of defining interfaces between TMOD service systems and project MOS, the catalog must be applied in conjunction with more detailed information covered in Deep Space Network / Flight Project interface design handbook[1,2], AMMOS capabilities catalog and adaptation guide[4], and others.

It is a TMOD policy that the TMOD Services Catalog shall include only services that are available at the time of the catalog issuing, or have funded deployment plans and dates.

Throughout this document, the term *service* is applied to mean the mission operations service and the term *customer* refers to a flight project Mission Operations System (MOS) organization or an experiment investigator.

2. Point of Contact and Applicable Documents

The Center Mission Service Manager (CMSM) at JPL TMOD Plans and Commitments Office will be the point of contact for making commitments to flight project customers on TMOD services, tools, and engineering support. For information about how to contact the CMSM, please access the home page at URL address: http://deepspace1.jpl.nasa.gov/920/.

The custodian of the TMOD Services Catalog is the TMOD System Engineering Manager.

Applicable Documents

(1) *Deep Space Network / Flight Project Interface Design Handbook*, Document No. 810-5, *Volume I: Existing DSN Capabilities*, Jet Propulsion Laboratory, Pasadena, California.
(2) *Deep Space Network / Flight Project Interface Design Handbook*, Document No. 810-5, *Volume II: Proposed DSN Capabilities*, Jet Propulsion Laboratory, Pasadena, California.
(3) *Multimission Ground Data System: Users Overview*, D-6057, Rev C, Jet Propulsion Laboratory, Pasadena, California, April 1994.
(4) *Advanced Multimission Operations System (AMMOS) Detailed Capabilities Catalog and Adaptation Guide*, D-5104, Jet Propulsion Laboratory, Pasadena, California.
(5) *Space Flight Operations Center (SFOC) Functional Design Document,* D-3752, Jet Propulsion Laboratory, Pasadena, California.
(6) *Deep Space Network / Detailed Interface Design*, Document No. 820-13, Jet Propulsion Laboratory, Pasadena, California.
(7) *Telemetry Channel Coding*, CCSDS 101.0 B-3, May 1992, The CCSDS Secretariat, NASA Head-quarters, Washington, DC 20546.
(8) *Packet Telemetry*, CCSDS 102.0 B-4, November 1995, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.
(9) *Telecommand, Part 1: Channel Service*, CCSDS 201.0 B-2, November 1995, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.
(10)*Telecommand, Part 2: Data Routing Service*, CCSDS 202.0 B-2, November 1992, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.
(11) *Telecommand, Part 2.1: Command Operation Procedures*, CCSDS 202.1 B-1, October 1991, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.
(12) *Telecommand, Part 3: Data Management Service*, CCSDS 203.0 B-1, January 1987, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.
(13) *Time Code Formats*, CCSDS 301.0 B-2, April 1990, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.
(14) *Radio Metric and Orbit Data*, CCSDS 501.0 B-1, January 1987, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.

(15) *Space Link Extension Services— Cross Support Reference Model*., *Part 1:* Recommendation for Space Data Systems Standards, CCSDS 910.4-B-1. Blue Book. Issue 1. May 1996.
(16) *Space Link Extension — Cross Support Concept Part 1* . CCSDS 910.3-G-1. Green Book. May 1995.
(17) *Space Link Extension Return All Frames Service*, CCSDS 911.1-R-1, Red Book, Issue 1.
(18) *Space Link Extension Forward CLTU Service*, CCSDS 912.1-R-1, Red Book, Issue 1.
(19) *Space Link Extension Forward Space Packet Service* , CCSDS 912.3-R-1, Red Book, Issue 1.
(20) *Space Link Extension Return Virtual Channel Frame Service,* CCSDS 911.2-R-1, Red Book, Issue 1.
(21) *Space Link Extension Forward TC Frame Service*, CCSDS XXX.X-W-2, White Book, October 1997.
(22) *Space Link Extension Service Management Specification*, CCSDS 910.5-W-1.12, White Book, January 1998.
(23) *A Guide to Capabilities Provided by The Office of Space Communications:* NASA Office of Space Communications, April 12, 1996.
(24) *Packet Telemetry Services*, CCSDS 103.0-B-1. Blue Book. Issue 1. May 1996.
(25) *Advanced Orbiting Systems, Networks and Data Links: Architectural Specification*, CCSDS 701.0-B-2. Blue Book. Issue 2. November 1992.
(26) *Lossless Data Compression,* CCSDS 121.0-B-1. Blue Book. Issue 1. November 1996.
(27) *Radio Frequency and Modulation System, Part 1 - Earth Stations and Spacecraft*, CCSDS 401.0-B, November 1994, The CCSDS Secretariat, NASA Headquarters, Washington, DC 20546.

3. Definition of TMOD Services

3.1 Standard Service and Tailored Service

Service, in its general sense, is "work done for others". In the TMOD context a service is work performed by the service system, i.e. the Deep Space Mission System (DSMS), using one or more tools, facilities, or people, that produces mission and science operations results for a customer. Services may be *standard* or *tailored*.

TMOD *standard services* are those defined in this document, i.e. the TMOD Services Catalog, from which customers can make selection for their needed services to support their missions operations without the expenditure of non-recurrent engineering.

A TMOD *tailored service* is one which requires substantial development effort due to the mission-dependent nature of the functions performed by the service or is one requested by customers for functionality different from a corresponding standard service offered in the TMOD Services Catalog. In either case, for fulfilling a tailored service, modification of TMOD capabilities with additional implementation effort will be needed at the cost of the customer.

3.2 Key Attributes of Standard Services

The TMOD standard services have the following key attributes -

(1) **Customer Relevance**: Services as perceived by the customers must be of value to the customers, packaged at a functional level, and expressed in the customer's terms. In other words, a service must be defined in terms of "what it provides" rather "how it produces". This implies isolating the lower level of details of the capabilities and activities from the customers while still providing visibility to the customers.

(2) **Pick-And-Choose**: The services must be selectable by TMOD customers. Subscription to a service by a customer should not require buy-in of other services which are not relevant to the customer's needs.

(3) **Plug-And-Play**: The use of any TMOD standard services (as distinguished from the tailored services) must be based on definitions which appear in the TMOD Services Catalog. Once a service, as it exists in the Services Catalog, is subscribed to, it must be readily available for use by the customer. It should not require any implementation effort beyond interface testing, configuration setup, and parameter table updates, by the TMOD as a services provider.

(4) **Standard Interfaces**: The use of the TMOD services, in terms of control and data interfaces, by the customers will be via standard interfaces. “Standard” interfaces include those formally established by standards organizations, those widely applied by the industry as de facto standards, and those defined by TMOD as common mechanisms to all customers. No additional development effort on the TMOD or the subscriber’s system other than that required for conforming to the standard interfaces will be necessary.

(5) **Service Control**: The customers will be allowed to directly control the service (within the bounds of the system’s capabilities and safety criteria).

(6) **Interoperability**: Services will be standardized, whenever applicable, to enable interoperability with other service providers whenever the same service is requested.

(7) **Performance Accountability**: Performance of each individual TMOD service subscribed to by a customer will be measurable and reportable.

(8) **Cost Accountability**: Services will be provided by the TMOD to a customer on a fee schedule basis. This means all standard services will be defined, structured, and priced in such a way that customers’ recurrent costs can be visible.

(9) **Mission Life Cycle Orientation:** Although each service by nature is for supporting the mission operations of flight projects, there are activities which must be conducted by TMOD during the design, implementation, and integration and test phases of the project in order to make a service available. These activities are inherent part of a service subscribed by the customer. As such, services are not defined according to the mission phases.

4. List of TMOD Standard Services

Table 4.1 contains a list of TMOD standard services. At present, 13 service families have been defined. Each service family consists of one or more types of service. A *service family* is a collection of functionally related types of services. A *service type* is characterized by the unique function performed and the result produced by the service. Within a service family, the various types of service are distinguished from each other by their level of processing involved or their value added function and, in some cases, the type(s) of source data.

Table 4.1 List of Standard Services (V.19)

1. Command services:	**6. Flight engineering services:**
• Command radiation service	**• Spacecraft health/safety monitoring service**
• End-to-end command delivery service**	**• Spacecraft performance analysis service****
	• Telecommunication link analysis service
2. Telemetry services:	**• Spacecraft time correlation service**
• Bit stream service*	**• Instrument health/safety monitoring service****
• Frame service	
• Packet service	**7. Sequence engineering service**:**
• Telemetry channel service	
• Data set service	**8. Science observation planning service**:**
3. Mission data management services:	**9. Ground communications & information**
• Short-term data retention service	**services:**
• Long-term data repository service	**• Ground network service**
• Archive product preparation service	**• Data transport service**
	• Collaborative service
4. Tracking & navigation services:	
• Raw radio metric measurements service*	**10. Radio science services:**
• Validated radio metric data service	**• Baseband measurements service**
• Orbit determination service**	**• Power spectrum display service**
• Trajectory analysis service**	
• Maneuver planning/design service**	**11. VLBI services:**
• Navigation ancillary data service	**• Narrowband measurements service**
• Ephemerides service	**• Wideband measurements service**
• Modeling and calibrations service	
• Gravity modeling	**12. Radio astronomy services:**
• Cartography	**• Radio astronomy service within DSN bands**
	• Radio astronomy service at special frequencies
5. Experiment data product services:	
• Level 1 processing service	**13. Radar science services:**
• Higher level processing service	**• Continuous save (CW) service**
• Photo product service	**• Binary phase coded (BPC) service**
• Science visualization service	**• Interferometric observations service**

Footnote: * label indicates a type of service, which is currently available only for legacy missions. It is no longer available to new missions.
** label shows a type of service which, although is not currently available, is planned for future missions. The following table shows the operational date, i.e. the launch date of the first supported mission, of each planned service:

Service Type	**Operational Date**
End-to-end command delivery service	3/2001
Orbit determination service	2/1999
Trajectory analysis service	2/1999
Maneuver planning/design service	2/1999
Spacecraft performance analysis service	4/2003
Sequence engineering service	4/2003
Science observation planning service	4/2003

5. Description of Service System

5.1 Service System in Customer Interface View

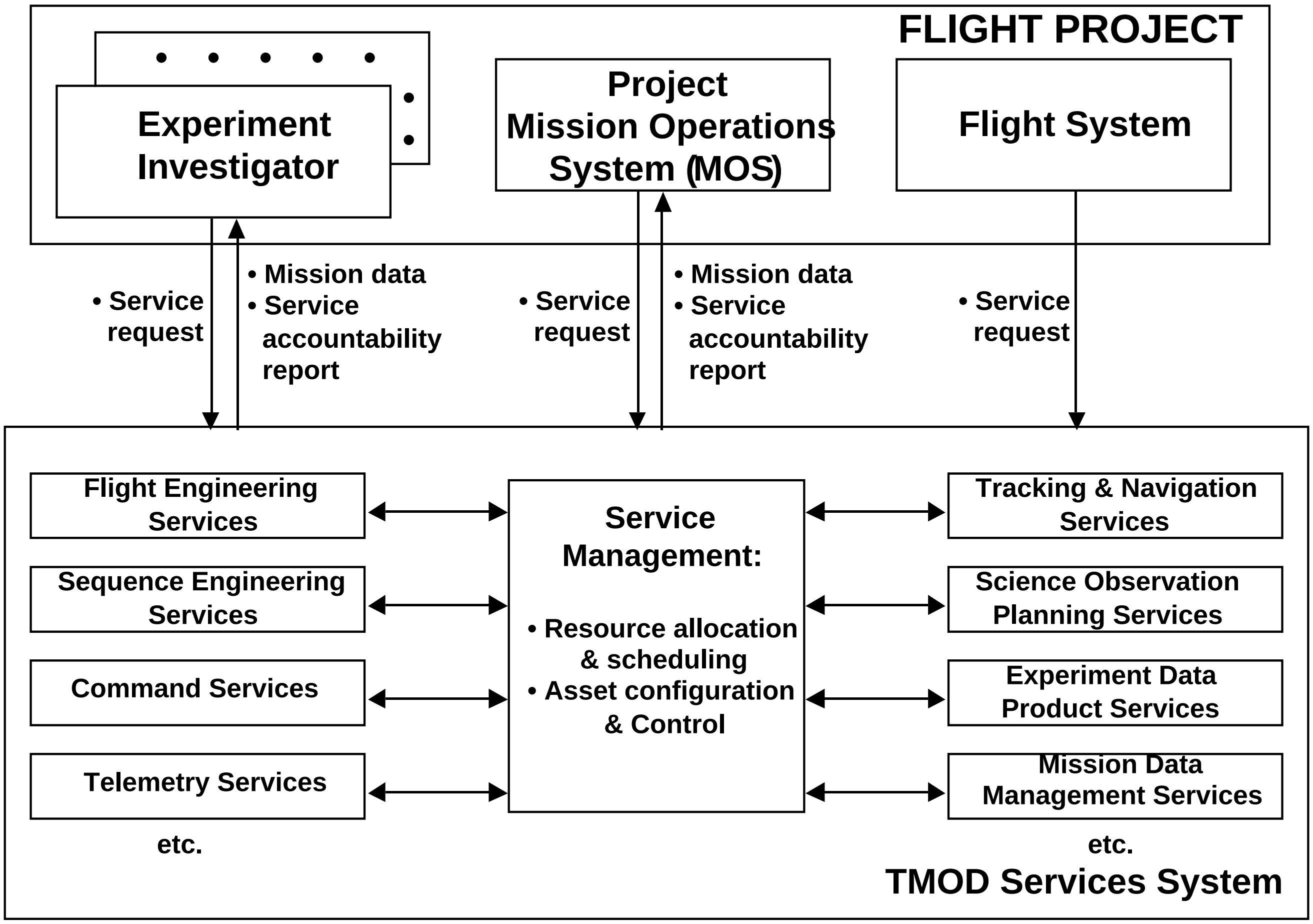
Figure 5.1 depicts the TMOD service system, the DSMS, from the customer interface view. Key characteristics of the service system from the customer interface view are as follows:

(1) Service Management function - The is a distributed function with its elements residing at the JPL Central and 3 Deep Space Communications Complexes (DSCCs). It includes (a) the allocation and scheduling of telecommunications and mission operations resources during service selection, agreement, and negotiation phases, (b) configuring and controlling the TMOD assets at JPL Central and each DSCCs for service production during service utilization phase, e.g. before, during, and after a pass. With respect to (b), the service management function "monitors" and "controls" the service production and provision process.

(2) Service requests are used by a customer, as a mechanism, to interface with the DSMS for services. Service requests are input to both (a) resource allocation and scheduling, and (b) asset configuration and control, providing a seamless interface to customers for their service need. In fact, the current processes, i.e. long range resource allocation, mid-range scheduling, near-real-time scheduling, and real-time configuration and control, will become a single integrated process.

(1) All services performed by the DSMS will be readily accountable to customers. Service accountability report detailing the quality, quantity, continuity, and latency (QQCL) or other performance metrics about each instance of service will be provided to customers after the fulfillment of the services.

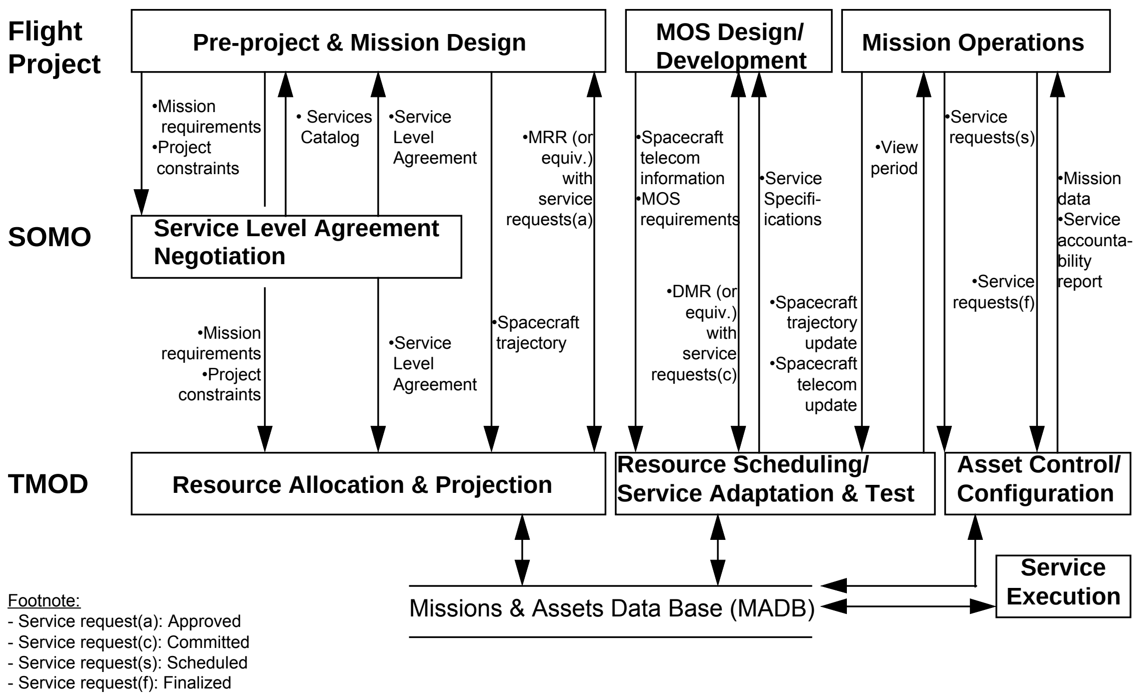
Figure 5.1 TMOD Service System: Customer Interface View



5.2 Service System in Life Cycle Process View

Figure 5.2 shows the process for customer to interface with TMOD for services over the entire project life cycle.

Figure 5.2 Customer Interface for Services: Process Over Project Life Cycle



5.3 Service System in Layered View

Figure 5.3-1 gives the layered view of the TMOD services system. TMOD services are at layers subservient to the customer's Project Mission Operations Function Layer which performs mission unique functions. This layer, i.e. the Telecommunications & Mission Operations (TMO) Services Layer, is further divided into 2 sub-layers: the Data Acquisition, Delivery, and Management (DADM) Services Layer, which includes data type-dependent, data content-independent, and mission-independent services, and the Application Services Layer which contains data type-dependent, data content-dependent, and mission-dependent services. The layer underneath is the Distributed Computing Service Layer which at present exist only in fragments of the various elements in the system, but will have to be built based on a coherent TMOD-wide design using different middleware technologies. The lowest layer is the physical asset layer containing the space/ground RF link, antenna of each tracking station, and the front-end equipment of microwave electronics, exciter, receiver, etc. at each station.

Key characteristics of the service system from the layered view are as follows:

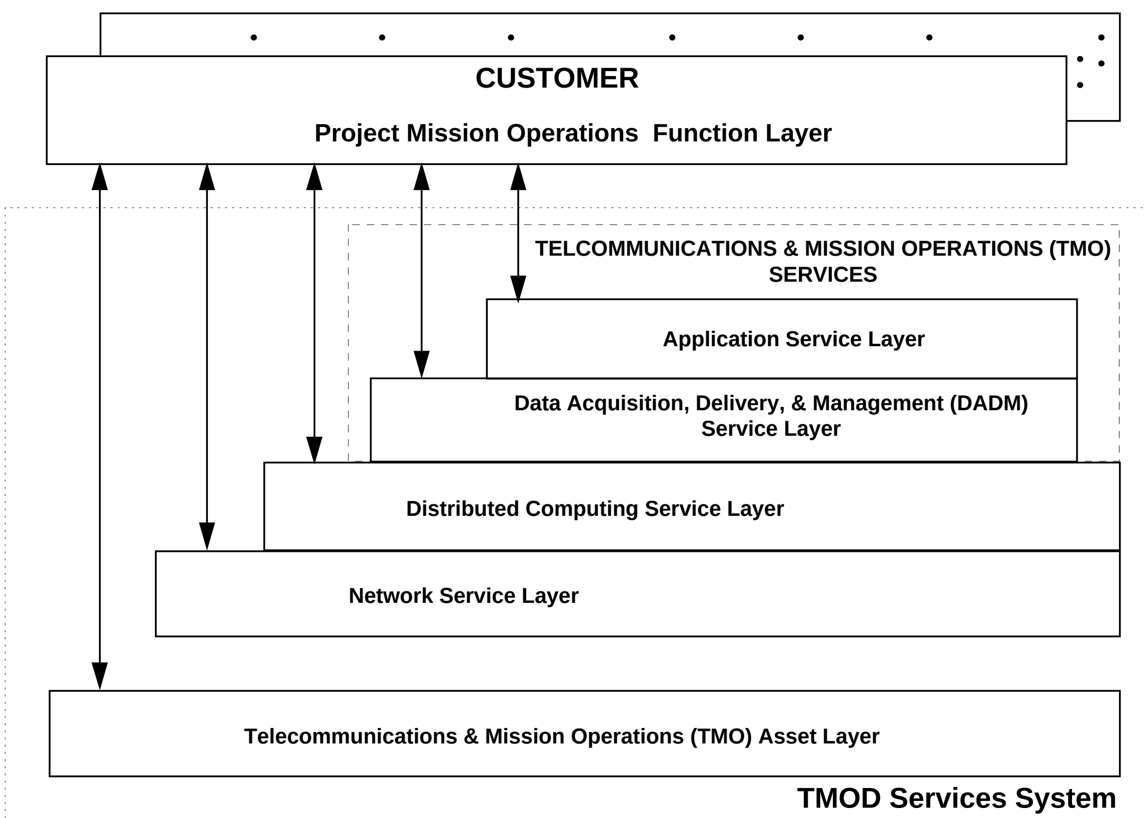
(1) Building block: Individual services are the basic building blocks of the service system architecture. Figure 5.3-2 shows how the individual types of services fit into the system layers.

(2) Common layer-to-layer interface: Interactions between any service elements of two different layers are through common interface mechanisms. While current systems in TMOD were not designed with clean layering and common layer-to-layer interfaces, it is expected that they will evolve over time to reach this goal.

(3) A service may be accessed directly by the customer, or it may support higher layer services.

(4) Multiple access points for services: The customer may access the service system at several points to accomplish the mission.

Figure 5.3-1 TMOD Service System: Layered View (Level 1)



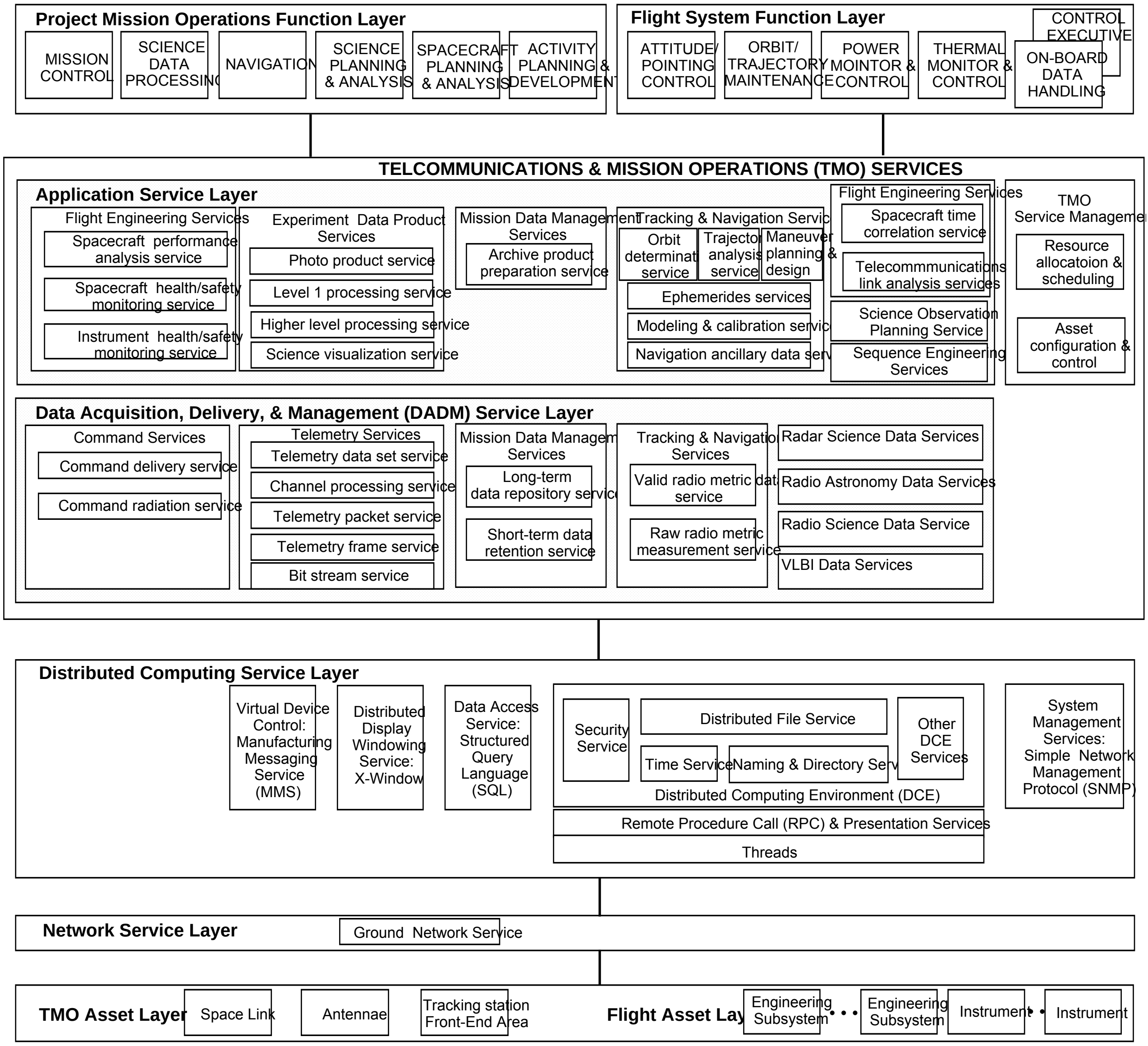


Figure 5.3-2 TMOD Service System: Layered View (Level 2)

5.4 Service System - Physical Assets

The TMOD services are visible and meaningful to customer in a functional sense. Many of these services are dependent on the spacecraft/ground links, the key physical assets available through its tracking networks. The Deep Space Network (DSN) provides operations support to Earth orbiting missions and deep space missions. Functions provided by the DSN include tracking, telemetry, command, and ground-based science data acquisition services.

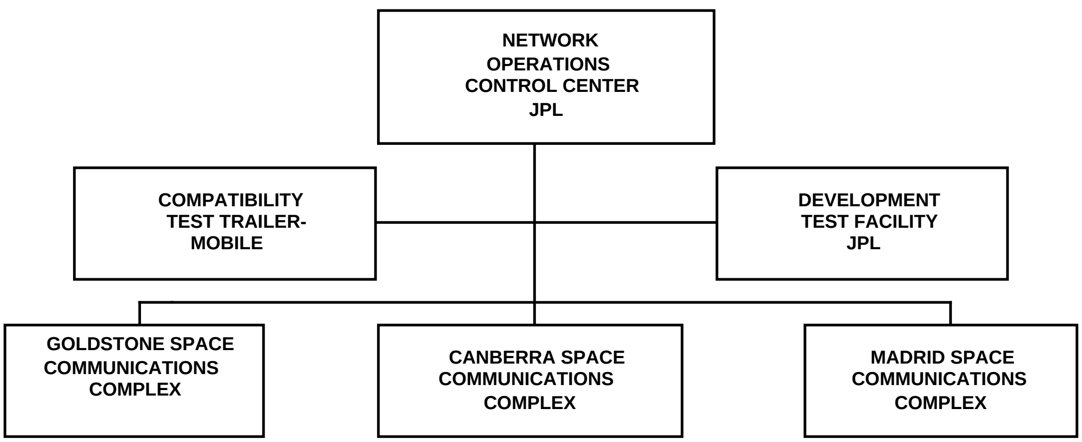
There are 3 Deep Space Communications Complexes (DSCCs), located near Goldstone, California; Madrid, Spain; and Canberra, Australia. Each complex has at least a 70-m antenna, a 34-m High Efficiency (HEF) antenna, a 34-m

Beam Waveguide (BWG) antenna, an 11-m antenna, and a 26-m antenna. These antennas communicate with and track spacecraft at S- or X-band (in some cases both) and Ku band at the 11-m station. Figure 5.4.3 gives a summary about the DSN assets and their locations.

The specific functions that the DSN performs are:

- To acquire telemetry data from spacecraft
- To transmit commands to spacecraft
- To track spacecraft position and velocity
- To perform very-long-baseline interferometry observations
- To measure phase and amplitude variations in radio waves for radio science experiments
- To gather other science data for ground based experiments

Figure 5.4.3 Deep Space Network assets and locations



DSS-13	34M	S,X,K	R&D
DSS-14	70M	S,X	
DSS-15	34M	X	HEF
DSS-16	26M	S	LEO/HEO
DSS-17	9M	S	LEO
DSS-23	11M	X,KU	OVLBI
DSS-24	34M	S,X	BWG
DSS-25	34M	X,KA	BWG
DSS-26	34M	X	BWG
DSS-27	34M	S	HSB

DSS-33	11M	X,KU	OVLBI
DSS-34	34M	S,X	BWG
DSS-43	70M	S,X	
DSS-45	34M	X	HEF
DSS-46	26M	S	LEO/HEO

DSS-53	11M	X,KU	OVLBI
DSS-54	34M	S,X	BWG
DSS-63	70M	S,X	
DSS-65	34M	X	HEF
DSS-66	26M	S	LEO/HEO

Key characteristics of the DSN physical assets are described in the Deep Space Network / Flight Project Interface Design Handbook[1,2].

6. Service Description

6.1 Command Services

The Command Services transmits command data to the spacecraft. The most rudimentary command service is the **command radiation service.** This service can be operated in 2 different data modes, i.e. stream mode and file mode. In stream mode, command data in the form of command link transmission units (CLTU) is received from the Project MOS and radiated to the spacecraft in real-time as a stream of data units. In file mode, a spacecraft command file is stored at a DSN tracking station or AMMOS prior to (or during) the pass and radiated to the spacecraft at a customer-specified time. In either case, this service ensures only the timely transmission of project's command data over the ground-to-space link. Error-free command delivery to the spacecraft is not guaranteed.

The more comprehensive service is the **end-to-end command delivery service**. It can accept either project command files prior to their time of radiation or in real time. This service controls command radiation while providing reliable, "error-free" data delivery to the spacecraft using the standard protocol defined as CCSDS Command Operations Procedure (COP-1)[10,11]. Table 6.1 summarizes the various service types, operation mode, and protocols for the command services.

Table 6.1 Command Services: Service Types, Data Modes, and Protocols

Data Mode / Service Type	Stream Mode	File Mode
Command Radiation Service	• Throughput* -- CCSDS Radio Frequency & Modulation[27] -- JPL CMD-4-8[6] • CLTU* -- CCSDS Radio Frequency & Modulation[27] -- CCSDS SLE** Forward CLTU Service[18]	• Store-&-Forward* -- CCSDS Radio Frequency & Modulation[27] -- JPL CMD-4-6[6] • CLTU File* -- CCSDS Radio Frequency & Modulation[27]
End-To-End Command Delivery Service	• Telecommand Frame -- CCSDS Telecommand, Part 2: Data Routing Service[10] -- CCSDS Telecommand, Part 2.1: CommandOperation Procedures[11] -- CCSDS SLE Forward Space Packet Service[19] • Telecommand Packet -- CCSDS Telecommand, Part 3: Data Management Service[12]	• Frame File • Packet File

* Supports both CCSDS and non-CCSDS CLTU structure
** SLE: Space Link Extension

Of the above command protocols, the throughput and store-and-forward protocols are currently available only for legacy missions. And they are being decommissioned, thus no longer available to new missions. The CCSDS CLTU and COP-1 protocols are planned for operational use in March 2001.

6.2 Telemetry Services

Telemetry Services acquire, process, store, and deliver telemetry data products to project MOS. The services are provided at 5 different levels: bit stream, frame, packet, channel data (i.e. telemetry measurement), and data set (i.e. file) level. Levels are selectable by the flight projects. Subscription to a higher level service automatically gives the functions of all lower services.

6.2.1 Bit Stream Service

The bit stream service provides a series of data units. Each data unit contains a stream of hard symbols or convolutionally decoded bits, in the order received, with an undetermined starting point, and without value-added processing such as frame-related decoding. Certain metadata is appended (e.g., time of receipt of a certain bit, spacecraft ID, spacecraft bit rate, SNR).

Since no measurement of the status of this product can be derived without further processing, the quality of this service cannot be guaranteed. This is a service available only to legacy missions and will be decommissioned soon.

6.2.2 Frame Service

Frame service is available to missions with either frame structure compliant with the CCSDS packet telemetry recommendation[7.8.24] or with a fixed length frame structure where each frame is preceded by a synchronization marker and a supported modulation technique. Within this service, the following options of frame output are available:

- all frame service[17]: provides both actual data frames and filler frames
- master channel service: provides data frames ordered within the master channel (selected by master channel with fill frames removed)
- virtual channel service[20]: provides data frames, i.e. virtual channel data units (VCDUs), selected, subset, and ordered within each virtual channel ID
- data extraction service: provides telemetry measurement data extracted from the insert zone of data frames according to customer-supplied decommutation table and/or extraction of the operations control fields (OCF) and their delivery to customers or other TMOD services (e.g. flight engineering or command services).

6.2.3 Packet Service

The packet service performs the extraction of packets from frames, i.e. virtual channel data units (VCDUs), and their delivery to project MOS or individual investigator. Compliance by the spacecraft with the CCSDS packet telemetry recommendation[8,24] is essential in order to use this service. Two options of packet output are offered to customers:

- packets extracted and ordered by Earth receive time (ERT)
- packets extracted and ordered by a combination of mission parameters, e.g. application ID, packet generation time, packet sequence count, etc.

6.2.4 Telemetry Channel Service

This service provides samples of telemetry measurements extracted from telemetry packets based on pre-defined decommutation rules or measurement identifications. Values of individuals samples are converted into engineering units (EU) from data numbers (DN).

6.2.5 Data Set Service

Data set service generates level 0 products by assembling telemetry packets or data units acquired for an observation cycle of given instrument or a collection of sampled engineering measurements of the spacecraft subsystems. For packets, the data set (or file) is composed of time ordered packets that each have the same packet ID. For time division multiplexed (TDM) data, these services are provided by extracting pre-selected parameters from TDM major frames to form decommutated data sets. Available options in processing are: removal of the artifacts, e.g. frame/packet headers, introduced for downlink transmission. The data sets are annotated with data quality and accounting information.

Data decompression may be performed on the ‘source data’ field for those specified packets using an algorithm corresponding to the compression performed by the source. Decompression is not explicitly part of CCSDS recommendations for packet telemetry. However, it can be considered to be an application-specific processing performed within the telemetry service. Once these packets are decompressed, the rest of the data set service can proceed normally. Decompression on data using any of the “standard” compression algorithms[26], e.g. Rice, ICT, JPEG, etc. is supported.

6.3 Mission Data Management Services

6.3.1 Short-Term Data Retention Service

The **short-term data retention service** provides for buffering and staging of customer's mission data. The data retention period can usually range from minutes to a week post-pass. This service is offered to temporarily safe-keep the mission data before they have been reliably distributed and routed to the customers during or after the pass.

6.3.2 Long-Term Data Repository Service

The **long-term data repository service** provides for life-of-mission data storage and retrieval in support of mission operations. The service provides a catalog to track all data sets and files in the mission repository. Users may query this catalog for data to be sent to them or re-staged on-line for retrieval. Data can be retrieved by time and data type and provided to the customers either electronically or on physical media.

Data in the mission data repository include stream data and file data. The data may be stored on-line or off-line. Data types include the telemetry data--spacecraft engineering and instrument housekeeping data in raw and channelized forms, science instrument frames and packets, and flight computer memory readouts, quality and accountability data, navigation ephemerides, commands, activity schedules, etc.

6.3.3 Archive Product Preparation Service

Along with the long-term data repository service is the **archive product preparation service** which provides the packaged data products into the form suitable for archiving at facilities such as the Planetary Data System.

6.4 Tracking and Navigation Services

6.4.1 Raw Radio Metric Measurement Service

This service provides radio metric observables based on measurement of phase and light time delay of the modulated RF signal acquired by the tracking stations. The data is not validated, except for a limited number of internal data validity flags, e.g. signal in lock, signal-to-noise ratio. The data are available electronically and the format is dependent upon the type of tracking station. All radio metric measurement services are also available as validated data via the Validated Radio Metric Data Service. It is recommended that users utilize the latter service.

6.4.2 Validated Radio Metric Data Service

The formats in which radio metric data is represented include a substantial amount of configuration data necessary for gleaning navigational use from the data. Due to a number of scenarios, this configuration data may be incorrect, rendering the radio metric observables unusable. The Validated Radio Metric Data Service validates incoming data and, when possible, fixes incorrect configuration data and supplies missing data (such as transmitter frequency). Data which can not be validated may be delivered to the customer, but it is identified as such. All Doppler, ranging, and angle data are validated, and all data are delivered in the same DSN format, TRK-2-18. It is recommended that all customers use validated data rather than raw data. To receive validated data, the subscriber simply requests the service and the specified data type.

6.4.3 Orbit Determination Service

TMOD provides to the subscriber an option to request an orbit determination service rather than simply requesting raw radio metric tracking data. With this service the user receives updated trajectory solutions for the subscriber's spacecraft. The subscriber identifies the accuracy to which the spacecraft's trajectory must be known as a function of time. If the accuracy requirement is a prediction requirement, then the customer must also provide information as to how far in advance the trajectory knowledge must be determined. Based on these requirements, the orbit determination service will determine a tracking scenario to meet this request, schedule the needed resources, and process the data to provide the customer with spacecraft trajectory knowledge or prediction to the specified accuracy. Because of the geometry dependencies and scheduling requirements, the accuracy requirements for orbit determination services must be defined three to six months in advance for deep space missions and several weeks in advance for Earth orbiting missions. The customer will receive the spacecraft trajectory at requested times (in NAIF SPK format) and the associated uncertainties. The orbit determination service is offered in a few different ways depending on data types and processing modes. A brief description is as follows.

6.4.3.1 Radio Metric Orbit Determination

The radio metric orbit determination provides the orbit determination for those customers with Earth orbiting or deep space missions who rely exclusively on radio metric observables. It includes launch support and support of transfer phases of missions. Trajectory updates are available at predetermined intervals, but thirty minutes to two hours, at minimum is generally required for the processing of data. The limiting accuracy of this capability is dependent on spacecraft trajectory.

6.4.3.2 Automated Orbit Determination

An automated orbit determination is performed to acquire radio metric data and automatically process them to provide the customer with near real-time (within 2 minutes) updates of the current best estimate and prediction of the spacecraft's trajectory. Additionally, smoothed reconstructions of the spacecraft's trajectory are available at predetermined intervals (as frequently as twice per hour). Users may receive update information and reconstructed trajectories as they become available. The accuracy of solution that this capability can provide is dependent on spacecraft geometry and available data types. The automated orbit determination can currently process Doppler and ranging data.

6.4.3.3 Optical Orbit Determination

This capability provides orbit determination services related to the use of optical measurements from an on-board camera. At the request of the customer, it can: 1) provide a performance analysis for a given on-board image acquisition system, 2) plan a schedule of observations to meet a customer defined trajectory accuracy either in conjunction with radio metric tracking or with optical data alone, or 3) process the optical images (telemetered from the spacecraft) either alone or with radio metric data to provide an updated spacecraft trajectory. As with the other orbit determination capabilities, the user requests a trajectory with a given accuracy over a time interval. The customer must specify if this accuracy requirement is relative to a specified target body (e.g. a planet or an asteroid) or inertial. If a trajectory prediction is required, the customer must specify how far in advance the prediction is required.

6.4.3.4 GPS Orbit Determination

Analogous to the optical orbit determination service, the GPS orbit determination applies an on board measurement optionally in conjunction with ground radio metric observations. However, rather than on-board imaging data, the on-board observations are from a GPS receiver on the spacecraft. If only GPS observations from the spacecraft are processed accuracies of 1 to 10 meters are achievable. If near simultaneous GPS observations from ground stations are also processed, then trajectory accuracies of less than 10 cm are feasible. As with other orbit determination capabilities, the customer must request the required accuracy as a function of time and identify how far in advance prediction accuracies must be known.

6.4.4 Trajectory Analysis Service

This service provides flight path prediction, reconstruction, and/or optimization to service subscribers. Flight path prediction consists of generating a detailed trajectory based upon state vectors, and associated spacecraft maneuver and body force modeling parameters. This allows for the generation of reference trajectories to be used for the tracking and mission predicts. Flight path reconstruction consists of generating a posterior reference trajectory based on orbit determination solutions and force models provided either by the customer or the orbit determination service. The trajectory optimization service will provide an optimized trajectory (from a deterministic ΔV perspective) based either on an approximate trajectory provided by the subscriber or based on a series of trajectory constraints (e.g. flyby conditions, entry conditions, & times).

6.4.5 Maneuver Planning & Design Service

This service provides propulsive maneuver analysis for flight missions and for future mission analysis. Based on a reference trajectory, the subscriber can request injection dispersion and probability of impact analysis for a specified launch vehicle as well as required aim-point biasing to meet planetary quarantine requirements. The subscriber may also request statistical ΔV analysis to characterize propellant needs, based on a trajectory, an expected orbit determination performance, and spacecraft thruster characteristics. This analysis will provide to the customer the optimal placing and sizing of maneuvers as well as estimates of the mission propellant needs. Orbit maintenance maneuver design, or the design of maneuvers required to change the orbit for the next mission phase is also available.

6.4.6 Natural Body Ephemeris Services

Natural Body Ephemeris Services provide ephemerides for all planets, most natural satellites, and several thousand comets and asteroids. The subscriber requests the service by specifying a period of time, the body or bodies of interest, and, if relevant, the desired accuracy of the ephemeris. If an ephemeris is already extant, which covers the desired period to the desired accuracy, it is immediately available. If the ephemeris is not available to the required accuracy, it may be possible to generate an improved ephemeris based on reprocessing of existing data or by acquiring additional data (generally for comets & asteroids). It may require from months to years to acquire the needed data and generate the new ephemeris. If the subscriber wishes, the service includes all of the analysis and scheduling of data acquisition.

6.4.6.1 Planetary Ephemerides

A single planetary ephemeris includes the trajectories (represented as polynomials over arbitrary time intervals) of the Sun, the Earth, the Moon, and 8 planetary system barycenters relative to the solar system barycenter. The accuracies to which each of the planets is known vary from the order 1 km for Venus and Mars, to the order of 10,000 km for Pluto.

6.4.6.2 Satellite Ephemerides

A single satellite ephemeris data set includes the ephemerides of a set of natural satellites and the parent planet relative to the barycenter of the particular planetary system. Satellite ephemerides are based on ground observations, radar measurements, and measurements from previous interplanetary missions.

6.4.6.3 Asteroid & Comet Ephemerides

Ephemerides are available for 14,000 asteroids and comets, including main belt asteroids and many Earth crossing asteroids and comets. An ephemeris can be generated at user request for any one of these bodies.

6.4.7 Modeling & Calibration Services

This service provides the subscriber with calibrations needed to process tracking data to the fullest accuracy possible. Calibrations specifically related to the data acquisition hardware are automatically delivered to subscribers of those data. These calibrations deal with systematic error sources which affect data.

6.4.7.1 Terrestrial Frame Tie

In order to process DSN radio metric data, the subscriber must know the inertial position of the receiver and, if appropriate, the transmitter at the time of the measurement. Although the locations of DSN antennas are known to within centimeters and the basilicas between them to millimeters, the variations in polar motion and the rotation rate of the Earth can move the inertial position by much larger amounts than this. The terrestrial frame time data provides a temporal model for the orientation of the Earth's pole and the spin rate based upon VLBI observations and tracking of GPS satellites. This data provides the subscriber with an instantaneous knowledge of the inertial position of a crust fixed location on the Earth's equator to 30 cm. A posterior knowledge on the order of 1 to 5 cm is available after two to three weeks delay.

6.4.7.2 Transmission Media Calibrations

Radio signals affected by the transmission media through which the signals pass. The most significant of these are the Earth's troposphere and ionosphere. In order to fully achieve the data accuracies discussed in the previous sections on data services, it is necessary to calculate adjustments for the delays due to these. The media calibration models are based upon tracking of GPS satellites at two frequencies. The format of these calibrations is a history of zenith delay over a pass and a mapping function to map them to the appropriate altitude.

6.4.8 Gravity Modeling

The subscriber to the gravity modeling service can request and immediately receive an existing spherical harmonic gravity model for one of three bodies: Venus (120th degree and order), the Moon (75th degree and order), or Mars (50th degree and order). The subscriber can also request an improved gravity model based on provided tracking data; the improvement in the field will be based upon the accuracy and coverage of the data. The reduction of the tracking data and the generation of the improved gravity model will require some time to process. The amount of time is a function of the density of the data and current state of an existing model and will vary from a few days to a few months.

6.4.9 Cartography

The cartography service provides the subscriber with positions of landmarks on a body's surface which can be related to an inertial reference frame. The subscriber can either request the best current knowledge of a landmark based on previous analysis or in some cases, such as Mars landmarks, request an improved location estimate based on reprocessing of extant data. Finally, the customer may provide (or request to have provided from other services) image data and a reference trajectory and have the reference location of a specified landmark determined. The image data must include the inertial pointing of the imager and the time that the image was taken.

6.4.10 Navigation Ancillary Data Service

The Navigation Ancillary Data Service provides reduced and interpreted ancillary dataset to space scientists pertaining to their experiments. These data include spacecraft ephemeris, planetary ephemeris and constants, instrument descriptions, camera pointing, events about spacecraft and instruments, packaged in such a way that they are self-identifiable and correlated to science observations.

6.5 Experiment Data Product Services

The Experiment Data Product Services provided by TMOD to flight projects include the generation of a variety of experiment data products from the acquired science instrument data. The processing involved in generating these products applies high degree of multi-instrument capabilities, thus resulting in significant reduction in processing time and cost, and increase in product interpretability to the science team.

6.5.1 Level 1 Processing Service

Level 1 processing applies calibration information and ancillary data to remove the instrument signature from the data. The Level 1 processing service provides products generated in non-real-time after the arrival of the telemetry. Depending on the desires of the science team, the processing includes adding ancillary or correlative data, removal of instrument signature, mathematical transformation of time series data, reformatting of the data, and data quality check.

6.5.2 Higher Level Processing Service

Higher level processing converts the level 1 data to science parameters. The higher level processing service provides experiment products at level 2 or above. The processing can generally be selected from the following: color reconstruction from multiple exposures, cartographic projections and mosaics, animation sequences, mathematical transformation of time series data, visualization products portraying data from multiple instruments, and visualization products of multispectral data.

6.5.3 Photo Product Service

Photo products containing any level of products includes enhancement applied to improve interpretability and annotation specified by the science team. Annotation can include engineering data, ancillary data (e.g. spacecraft attitude, instrument pointing, etc.), N-dimensional histograms, gray scales of color bars, etc.

6.5.4 Science Visualization Service

Science visualization service takes science image data as input to produce still and animated visualizations for the planetary exploration missions, e.g. animated series for flights around Mars, Venus, Miranda, etc. The digital products of science visualization, when incorporated with navigation, ephemeris, or other imagery data, can be used for both science data analysis and science observation planning.

6.6 Flight Engineering Services

The Flight Engineering Services provide the spacecraft performance analysis, spacecraft and instrument health and safety monitoring, telecommunications link analysis, and spacecraft time correlation. Engineering support to assess spacecraft analysis on-board automation and autonomy design trades vs. requirements will be supported. In addition, Flight Engineering Services provide the engineering and planning required for execution of the real-time and non-real-time mission operations. The Flight Engineering Services also provide a project focal point for operations coordination, initiating commanding, on-line or on-call real-time anomaly response, and operations of non-standard/special circumstances.

6.6.1 Spacecraft Health and Safety Monitoring Service

The Spacecraft Health and Safety Monitoring Service provides a first level monitoring and verification of the spacecraft health and operation, based upon project provided limits. Automated spacecraft alarm detection and project alert mechanism is provided based on telemetry and monitor data. When an out of limits condition is found, automatic notification via e-mail and/or pager is made to mission control personnel and other project designated personnel.

This is primarily a real-time monitoring function. As part of the service, anomaly corrective action is limited to commanding the spacecraft (usually via safing commands) in real-time based on the “cookbook” procedures and contingency plans supplied by the project MOS.

6.6.2 Spacecraft Performance Analysis Service

The spacecraft/instrument performance analysis service provide system-level analysis of spacecraft and science instrument performance and health. By correlating the assessed behavior of power, thermal, guidance and dynamics, telecommunications, and other on-board conditions from a spacecraft system perspective, the spacecraft performance analysis service evaluates spacecraft and instrument status against expected performance. The spacecraft performance analysis service also provides uplink support. Support includes planning and coordination of commanding requests, and the design and development of engineering sequences. The service also provides real-time operations database maintenance, configuration control, and coordination. In event of unexpected spacecraft performance or anomaly condition, it initiates recovery actions, first by isolating the problem area within the spacecraft, and secondly by initiating Project-provided recovery procedures. Recovery actions may include real-time commanding, e.g., safing commands associated with contingency response procedures. The Service can provide automated or human response to spacecraft and instrument anomalies as negotiated with the flight project. Well understood anomalous conditions may be corrected with pre-generated or pre-canned commands provided by the project. In the event of a significant spacecraft malfunction, spacecraft subsystem expertise shall be available from the spacecraft builder, or other knowledgeable source from within the Project.

6.6.3 Telecommunications Link Analysis Service

Telecommunications Analysis Service provides the means for a flight project customer to plan the communications configuration and capability between a spacecraft and the tracking stations of the Deep Space Network and then to assess the resulting performance against the plans. Planning requires the prediction of signal level, signal-to-noise ratio, and data error rate in terms of link models. Assessment requires the comparison of the values of these quantities as reported in spacecraft telemetry data and station monitor data against the predicted values.

The primary communications links are at any frequency supported by the stations. They include command, telemetry, and radiometric (closed-loop Doppler and turnaround ranging). The telecom analysis service can plan and assess relay links as well as those direct with the DSN.

A flight project can use the telecom analysis service at any time from initial spacecraft and mission design, through the implementation of a flight operations system, and into flight operations when the spacecraft-station communications links are active. It includes the following standard components:

- Adaptation of the telecom link prediction and assessment tools. The tools provide a standard prediction, forecasting, and link performance comparison capability.
- Set-up of link performance analysis displays involving standard or custom processing of in-flight data for comparison with predictions.
- People to operate the tools and so provide pre-defined predictions or communications link analysis reports.
- People to participate in the project's flight operations teams as telecom analysts at an agreed upon level of support.
- Documentation of the project's telecom plans and support requirements (such as Mission Service Tables), telecom configuration and performance predictions, and actual telecom performance relative to predictions.

6.6.4 Spacecraft Time Correlation Service

TMOD offers a Spacecraft Time Correlation Service which, with a cooperating spacecraft implementation, enables correlation of the time of spacecraft events with Coordinated Universal Time (UTC) and the time these events would be observed on the ground (earth received Time, UTC). Specifically, this service provides:

- Validated correlation coefficients to convert spacecraft clock counts into spacecraft event time (UTC) for acquired data.
- Predicted correlation coefficients to convert spacecraft clock counts into spacecraft event time (UTC) for future events (e.g., command execution times). This is achieved by modeling and monitoring the spacecraft clock and its drift characteristics.
- The corresponding earth received time (UTC) for Validated or Predicted values of spacecraft clock count or spacecraft event time (UTC).
- On-board UTC If the spacecraft carries an adjustable clock, TMOD can provide the service of measuring its offset from UTC (as above) and routinely commanding it to drift ahead or behind to eliminate or reduce the correlation coefficients to acceptable bounds. This enables the customer to use the spacecraft time tags as they appear in the data, without corrections.

To obtain this Service, the spacecraft timing implementation of future missions must:

- use CCSDS Source Packets with time tags (in the secondary headers) which are derived from the spacecraft master clock which is being measured as part of this service,

- use one of the CCSDS Time Code Formats[13],
- use CCSDS Frames,
- read the spacecraft clock at the time a specific bit of a telemetry frame leaves the spacecraft, and
- report this time, plus the corresponding frame sequence number and Virtual Channel in either a dedicated Time Calibration packet or the Operational Control Field of a related frame.

6.6.5 Instrument Health and Safety Monitoring Service

The Instrument Health and Safety Monitoring Service provides a first level monitoring and verification of the instrument health and operation, based upon project provided limits. Automated instrument alarm detection and project alert mechanism is provided based on real-time and playback instrument engineering data and quick-look science data data. When an out of limits condition is found, automatic notification via e-mail and/or pager is made to science team and other project designated personnel.

This is primarily a real-time monitoring function. As part of the service, anomaly corrective action is limited to commanding the instrument (usually via safing commands) in real-time based on the "cookbook" procedures and contingency plans supplied by the science team.

6.7 Sequence Engineering Services

The Sequence Engineering Services provides for the design, development and execution of the uplink process in support of flight projects execution of the Mission Plan. The uplink process is a method by which science and engineering objectives are processed, integrated and translated into a "sequence" compatible with spacecraft systems. A sequence is a set of commands or requests for on-board and/or ground activities, either stored in on-board sequence memory or sent as non-stored (real-time) commands. The service is two-fold in nature:

- Functional design and implementation of the operations and data systems associated with a flight unique uplink process – It includes the uplink process requirements, and design definition, and the sequence software requirements, design implementation, and integration and test. The design of the uplink process will include assessment of onboard autonomy and automation vs. project requirements.

(2) Provision of sequences during mission operations phase – This includes some or all of the following activities:
  - Sequence activity planning and integration of science, engineering, navigation, and ground activities based on the project mission plan.
  - Sequence input generation, integration, and product generation of sequence activities.

- Sequence validation.
- Service requests or keywords file (legacy missions) generation for each planned station pass consistent with the sequence.

6.8 Science Observation Planning Services

The Science Observation Planning Service designs and integrates the science observations, according to science opportunities identified by the investigators, to produce a conflict free timeline of activities that will be used to generate commands for the instruments. The service employs a generic planning tool augmented with instrument models, target body models, photometric models, data from other missions or instruments, etc. to validate the various activities and identify conflicts. Resolution of conflicts is accomplished by priorities established by the investigators. Since science observation planning often begins months or years before the events, observations may need changing to account for discoveries or new information about the observation.

The service is intended to support both remote-sensing and in-situ science investigations.

6.9 Ground Communications and Information Services

Ground Communications and Information Services provides a reliable and secure communications infrastructure capability to flight projects.

6.9.1 Ground Network Service

Reliable communications are provided from the stations or JPL to the user's site, and the end-to-end integrity of the network is maintained by TMOD with a 24-hour per day, seven-day per week communications staff. Communication paths for data, voice, and video network between the mission control center, various PI facilities, various contractor facilities, the launch site, JPL, and DSCC are established via wide area network circuits and/or local area networks.

(1) Wide Area Networks: Ground communication circuits are provided from the antenna stations or JPL, to the user's site. TMOD orders the wide area network services from the NASA Integrated Service Network (NISN) Program. In turn, NISN orders domestic services through the General Service Administration's FTS 2000 contract (i.e., AT&T), and arranges special contracts for international circuits. Circuits that are used to carry spacecraft data are usually ordered with carrier guarantees for 20-minutes-to-isolate problems, and two-hour-to-restore.

Dedicated channels from the antenna stations through JPL can often be provisioned by multiplexing channels through a shared NISN circuit.

(2) Local Area Networks: Local area networks are installed and maintained by the TMOD system administrators. The most common LAN technology is Ethernet (10 or 100 Mbps), but several Fiber Distributed Data Interface (FDDI) networks (100 Mbps) are in place to act as backbone networks for high-speed access among various locations.

(3) Data Networks: Data networks are based on the Internet Protocol (IP). Among hosts at a particular site, Ethernet hubs and virtual LAN technology are used for ground communication. IP routers are used to transmit data traffic across a path of dissimilar networks. Routers and hubs may be installed and configured by the TMOD system administrators.

(4) Voice and Facsimile (Fax): TMOD supports 12 dedicated voice loops for real-time communications between project operations centers (POCs) and antenna station operations. Compressed voice technology (from normal 64 kbps, down to 12 kbps) is usually used for these communications.

Fax transmission occurs over the same voice paths.

(5) Remote Communications Terminal (RCT): TMOD may provide a dedicated terminal for a user's site that includes circuit-termination equipment, voice interface equipment, a router, and remote testing equipment. The RCT may be configured for unattended operations.

6.9.2 Data Transport Service

At the DSN antenna stations, the station communications processor (SCP) receives all data generated by the digital receiver and telemetry processor. It may pass the data directly to the Project MOS and/or PI's sites as a low-latency UDP (User Datagram Protocol) stream or forward the stream to a reliable network service (RNS) that guarantees no lost IP packets. The RNS delivery service has several user options that are described below.

Low-Latency Service:. The low-latency service is used to feed a real-time stream of spacecraft data to the user in the shortest possible time (less than one-second latency). This service is similar to the (now obsolete) NASCOM 4800-bit switched service. No error recovery is made; data packets that may be damaged by noise in the ground communications circuit are simply discarded.

Reliable Network Services:

Timely Service - Timely Service transmits a reliable real time stream to the user, but if the stream is delayed due to ground network congestion, any data older than 10 seconds is discarded. A simultaneous stream (complete) is forwarded to a data repository for later delivery. This makes it possible for the user to keep abreast of activity on the spacecraft, and have confidence that the data is complete within the specified time limits.

Complete Service - The Complete Service is used for most stream data. Congestion in the ground network may cause delays, but all the data will be delivered in the stream, and a simultaneous stream (complete) is forwarded to a data repository for later delivery. Delivery is guaranteed within 5 minutes.

Off-Line Service - All RNS data is stored for later, off-line, delivery. Delivery is accomplished using the File Transfer Protocol (FTP). After prior registration with the operations Communications Chief, the data may be delivered by FTP 1) automatically, 2) on command by the Communications Chief, or 3) on command by the user using a Web interface.

6.9.3 Collaborative Service

Collaborative Service is further categorized into the following:

(1) Distributed File Service: AFS servers, which provide a distributed file system, are available throughout DSMS and are planned for Mars operations at Lockheed Martin Aeronautics (Denver).

(2) Distributed Computing Environment (DCE): DCE servers are located at all DSN sites and JPL. These servers may be used by missions for creating a distributed application architecture.

(3) Collaborative Environment: The Collaborative Environment is a system of desktop videoconferencing systems and application sharing that facilitates person-to-person engineering and operations within TMOD. Turnkey systems are available that interoperate with other TMOD and NASA systems.

6.10 Radio Science Services

The Radio Science Data Services provide for the collection and distribution of high-quality radio science products. These products include open-loop recording of selected passbands as well as Doppler and range data, as obtained and processed from one-, two-, or three-way space links from a mission flight element. The **baseband measurement service** includes capabilities for: transmission of a high-power RF signal at S-, X- or Ka-band; capturing of an RF signal at S-, X- or Ka-band; amplification; down-conversion; open-loop (predict driven pass-band recording) or closed-loop (Doppler and range processing of space link carrier) tracking; buffering; routing by virtual channel identifier (as well as recording on-site); and delivery of data and monitor to geographically-dispersed recipients in near-real-time or on a delayed basis. This service description is generally restricted to details of the open-loop capability of the Radio Science Data Service; Doppler and range services are provided by the

Radio Metric Measurement Service and details of these products are found in the Radio Metric Measurement Service entry.

A **spectrum display service** partitions the received signal into bins of specified width and measures the amplitude and phase in each. The resulting spectra can directly measure physical phenomena or the effect that such phenomena have on a known radio signal.

6.11 VLBI Services

A variety of VLBI services using **Narrowband VLBI** and **Wideband VLBI** systems are provided. These include raw data, processed VLBI data in form of relative signal delay and delay estimates between two antennas, platform parameter (Earth rotation and polar motion) estimates and radio source position catalogs. Raw data, digitized and formatted samples of an open loop signal, is available from a wide bandwidth system in non-real time on VLBA (Very Long Baseline Array) compatible tapes. This data is primarily used for Radio Astronomy. When VLBI data from two or more antennas is cross correlated, an estimate of the signals relative phase delay and delay rate between the antennas is produced. The delay and delay rate estimates are provide to users for further processing. This data is primarily used by Navigation teams for use in estimating spacecraft angular positions and rates. A service is also provided which analyzes the delay and delay rate data and produces estimates of changes in the Earth rotation and Earth's polar motion. Estimates are also provided for the angular positions of natural radio sources (e.g. quasars) which provide references against which spacecraft positions are measured.

6.12 Radio Astronomy Services

The Radio Astronomy Services support the use of the DSN as a science instrument for astronomical research that takes advantage of the unique capabilities of the network for scientific measurements. Typical radio astronomy experiments include measurements of microwave brightness, polarization, and spectral line emission/absorption of solar system bodies and natural sources of radio emission throughout the universe. Use of the DSN for Very Long Baseline Interferometry is described in **VLBI Services**.

The Radio Astronomy Services are intimately related to the DSN Science R&D programs and the Telecommunications and Missions Operations Technology (TMOT) programs. The science goal of these R&D programs is to realize the potential of the DSN to do what has not been done before -- to image the formation of a new star, to map the surface of an Earth-crossing asteroid, to use phased feeds to operate an antenna well above its design frequency. A primary objective of the Radio Astronomy Services is to maintain vital interfaces with the special purpose equipment developed by the R&D programs.

There are two categories of Radio Astronomy Services: (1) Experiments that use existing DSN downlink receiver bands, and (2) Experiments that require receive capability outside the DSN telecommunication bands at frequencies used for radio astronomy and/or rf bands with potential use for future DSN telecommunications.

6.12.1 Radio Astronomy Service within DSN Bands

Within the DSN downlink frequencies, the service provides conditioned IF distribution from S, X and Ka Band DSN radio frequency subsystems to special purpose receiving and data analysis subsystems. The latter are operated and maintained by various R&D engineering groups that differ among the three Deep Space Communication Complexes (DSCCs).

The service also provides monitor and control interfaces to DSN operational subsystems (e.g., antenna pointing, receivers, FTS) via Radar and Radio Astronomy special purpose control subsystems.

6.12.2 Radio Astronomy Service at Special Frequencies

For experiments requiring non-standard DSN radio frequency bands, the service supports the use of DSN antennas in receive-only mode using special purpose R&D microwave and receiving subsystems. On the 70-m antennas these subsystems are usually mounted in the R&D cones with feed systems located on the focal ring. On the 34-m BWG antennas the subsystems reside at one of the equipment mounting stations inside the rf-protective shroud.

The requirements for this service change as opportunities for new experiments arise and/or new technologies are developed. To accommodate these changes, the service provides monitor and control interfaces between DSN operational subsystems (e.g., antenna pointing, receivers, FTS) and the special purpose equipment via Radar and Radio Astronomy special purpose control subsystems.

6.13 Radar Science Services

The Goldstone Solar System Radar (GSSR) is a national scientific resource, developed by the DSN to support the exploration of the solar system. The GSSR is a dual-wavelength (3.5-cm and 12.5-cm), multi-aperture, high-power radar astronomy instrument with sensitivity to produce echoes from the inner planets, Earth's moon, Jupiter's Galilean satellites, Saturn's ring system and larger satellites, asteroids, and comets. Radar observations provide information about the target's orbit, spin vector, dimensions, topography, and surface geology (composition and structure), as well as the characteristics of planetary atmospheres and interplanetary space.

The Goldstone Solar System Radar provides a unique capability: it is the only 3.5-cm wavelength planetary radar in the world with sufficient power to probe the Solar System as far away as the orbit of Saturn. Moreover, it is the only fully steerable planetary radar system in the world. This characteristic makes it extremely valuable for observations of Near-Earth asteroids and comets which typically encounter the Earth at a wide variety of declinations. Thus the GSSR is complementary to the Arecibo Observatory radar system, which operates at 13-cm wavelength and uses a fixed antenna with limited visibility about the zenith.

The modes of operation of the GSSR fall into three broad categories, all at both 3.5-cm and 13-cm:

6.13.1 Continuous Wave (CW) Service

This service offers three CW modes, each with different hardware subsystems (Normally both circular polarizations are received in CW observations.):
a) Narrow bandwidth. This mode is offered for targets whose received bandwidth spreading is no more than 40 kHz.
b) Medium bandwidth. This mode is offered for targets whose received bandwidth spreading is no more than 8 MHz.
c) Wide bandwidth. This mode is offered for targets whose received bandwidth spreading is no more than 40 MHz.

6.13.2 Binary Phase Coded (BPC) Service

The possible modes provided by this service are divided by received polarization diversity and the number of stations receiving. The transmitter subsystem can supply either right OR left circular polarization signals in the BPC mode. The receivers at DSS-14 and DSS-13 can be configured for both or either circular polarization. DSS-15 and DSS-25 can only receive a single polarization, with RCP or LCP at the experimenter's choice.

6.13.3 Interferometric Observations Service

The GSSR can utilize the following baselines at the Goldstone Deep Space Communications Complex: DSS-14 to DSS-13, DSS-13 to DSS-25, DSS-13 to DSS-15, DSS-15 to DSS-25, and DSS-14 to DSS-25. The DSS-14 to DSS-15 baseline is too short for any practical application. In addition, the GSSR can transmit a CW signal designed to be used for direct imaging in both polarizations at the Very Large Array (VLA) of the National Radio Astronomy Observatories (NRAO, Socorro, NM) and the Very Large Baseline Array (data processing at the NRAO correlator in this case only, also in Socorro).

6.14 Service Management

Service Management is a special category of functions that must be performed by the customer and TMOD cooperatively to ensure that instances of services are properly planned and executed. It provides operational support to customers in preparation for the services they need, for controlling the production and provision of services, and for providing the visibility and accountability of TMOD service systems [Ref. to "CCSDS Space Link Extension - Cross Support Reference Model].

It includes (1) planning, scheduling, and allocating DSMS resources required for fulfilling the services (2) controlling and configuring TMOD assets required for providing the services. Depending on the service, a variety of mechanisms for asset configuration/control are offered:

(1) Internally-directed control: This is accomplished using 'service requests' mechanism as specified in Module OPS-6-24 of DSN Document 820-13. The service requests enable customers to specify, with a minimum effort on their part and without having to know the internal workings of TMOD physical assets, types of services expected for the preparation of service agreement during early phase of their projects and instances of specific services to be executed by TMOD during operational phase.

(2) Event control: This enables a customer to specify detailed, second-by-second control of events inside TMOD assets. This covers all of the capabilities of the old OPS-6-13 Keyword Files, including the ability to send directives to TMOD equipment.

(3) Direct control: This enables a customer to directly control TMOD assets at a control console local at TMOD.

(4) External control: This enables a customer to connect their control console to TMOD and thereby remotely control the operation of their scheduled activities.

7. Performance Characteristics of Services

This section addresses key performance characteristics of some of the standard services. Those services, which do not have any significant intrinsic performance drivers, are not covered here. To the extent possible, quantitative metrics is defined.

7.1 Command Services

7.1.1 Quantity

The quantity of command services is defined as the percentage of “acceptable” data units delivered by the service:

> # of “acceptable” data units delivered / # of “acceptable” data units input to the service
>
> (Note: “Acceptable” data unit means error free and complete data unit. Applicable data unit is CLTU, command frame, command packet, or command file, depending on the type of command service.)

For normal spacecraft activities, command services provided by TMOD achieve a performance of 96% in quantity metrics. For critical spacecraft activities, it is 99%.

7.1.2 Quality

The quality of command services is defined as the error rate for the uplinked data units. It is a function of the link margins, ground communications reliability, and uplink protocol.

Use of the CCSDS recommended Command Operations Procedure (COP) or other retransmission protocols can provide virtually error free, in sequence, command frames. The end-to-end command delivery service thus provides ultimate delivery of command data with zero error rate and a insignificantly low undetected frame error rate even at an uplink channel error rate of $1x10^{-5}$.

For the current command radiation service, due to some hardware problems in the modulation of subcarrier, especially at high data rate, there is a bit error rate of $1x10^{-6}$.

The end-to-end command delivery service provides ultimate delivery of command data with zero error rate and a insignificantly low undetected frame error rate even at an uplink channel error rate of $1x10^{-5}$.

7.1.3 Continuity

Gaps are not an issue in the file mode for command radiation service, because all the data is received by TMOD before it is transmitted. In the current throughput mode, there can be continuity problems due to communication path delay or to transmission strategy by project MOS; i.e. if the project MOS waits for an "echo" before sending the next CLTU, it may arrive too late for TMOD to maintain contiguous radiation. However, the command throughput service has features that can reduce the probability of a gap in the uplink.

Gaps are not an issue in the end-to-end command delivery service.

The continuity of command services can also be characterized by the availability of the command delivery process, which is essentially the average abort rate for command transmission. The current command services achieve an average abort rate of no more than 2 aborts in 10^7 transmitted bits. This is equivalent to 5×10^6 bits in mean time between aborts and 95% probability of abort-free operation for 250,000 bits.

7.1.4 Latency

The latency of command radiation service is defined as the time delay from the time of transmission of the command data units by the project MOS until its radiation. Latency is inherent in store-and-forward mode since a file of CLTUs must be transmitted in the sequence as they are stored. The radiation time can be specified. The achieved accuracy is 0.1 second or +/- 8 bit times, whichever is greater. In throughput mode, the latency is largely a function of the load on the wide area network between project MOS and tracking station. Inbound rate (to TMOD) should match uplink data rate ($\leq$ 2000 bits/sec at the present, and $\leq$ 4000 bits/sec after 1/2000).

The latency of end-to-end command delivery service is defined as the time delay from the time of transmission of the command data units by the project MOS to its delivery to the spacecraft by TMOD. In addition to the delay introduced by the underlying command radiation service as discussed above, one way light time is a dominant factor.

7.2 Telemetry Services

7.2.1 Quantity

The quantity of telemetry services is defined as the volume of "acceptable" data units delivered by the service -

> # of "acceptable" data units delivered / # of "acceptable" units input to the service

(Note: The number of "acceptable" data units used in the quantity metrics may be based on the number expected during the time period of service in which the RF input meets specified criteria. Applicable data units are frames and packets.)

It is the primary measure of data completeness. The performance of telemetry services in terms of quantity is about 98%. This is derived from an assessed probability of unrecoverable data loss based on "system availability" statistics of TMOD telemetry system

-- Availability of DSN telemetry system: 98.50% $\pm$ 0.47%
  0.47% is standard deviation on a month to month basis using historical data collected during 1/94-9/95

-- Availability of AMMOS telemetry system: 99.99%

Where:

"system availability" is defined as: $\dfrac{\text{(scheduled time - outage time)}}{\text{scheduled time}}$

7.2.2 Quality

The quality of telemetry services is defined as the error rate for the delivered data units over the end-to-end downlink path, where the definition of the data unit error rate differs depending on whether Reed-Solomon encoding (or other source codes) is employed or not. Applicable data units, in the metrics, are frames and packets. The following illustrate the typical performance of TMOD telemetry services in terms of quality metrics (assuming frame length and packet length are both about 10,000 bits):

(1) When Reed-Solomon encoding is employed, frame rejection rate or packet rejection rate defined as --

  # of data units which cannot be correctly decoded / total # of data units downlinked:

  - frame rejection rate $\leq 1\text{x}10^{-5}$ at bit SNR $\geq$ 2.5 dB
  - packet rejection rate $\leq 2\text{x}10^{-5}$ at bit SNR $\geq$ 2.5 dB

  The same rejection rate requires a bit SNR $\geq$ 6.0 dB if no convolutional code is applied as an innercode.

  Detectable error rate after Reed-Solomon decoding is 0 since these errors, introduced on the ground, are correctable or recoverable

(2) When Reed-Solomon coding is not employed, frame error rate or packet error rate defined as --

average bit error rate as calculated from either the sync words of all delivered frames or the symbol synchronizer and/or decoder SNR estimates:

- frame error rate = 3×10^{-2} at bit SNR $\geq$ 4.2 dB
- packet error rate = 3×10^{-2} at bit SNR $\geq$ 4.2 dB

Undetected error rate introduced on the ground is insignificant, 4×10^{-12}.

7.2.3 Continuity

Continuity metrics for telemetry services is based on the number of gaps in the total data units delivered to customers. A gap is defined as an occurrence of the loss of one or more consecutive data units. Applicable data units, in the metrics, are frames and packets (depending on the subscribed service type).

Telemetry services provided by TMOD can achieve a data gap rate of less than 1 gap out of 10,000 frames and 1 gap out of 10,000 packets (assuming frame length and packet length are both about 10,000 bits), excluding any data loss/error due to the following factors not attributable to TMOD:

(1) E_b/N_o, i.e. energy per bit vs. noise, less than 2.5 dB at frame error rate 10^{-5} according to the frame error probability vs. bit SNR performance curve for RS-encoded telemetry

(2) Adverse effects due to spacecraft fault

(3) Adverse weather condition at the tracking station

(4) Normal telemetry reacquisition due to data rate change or tracking mode change (e.g. 1-way to 2-way)

(5) Unexpected radio frequency interference (RFI)

Since human intensive effort is needed to accomplish the above continuity performance, customers are advised to design their mission data return strategy as tolerant to sporadic data gaps as possible. The gap rate at 1/5,000 packets should be expected as a nominal condition.

7.2.4 Latency

Latency metrics for telemetry services is defined as the time delay from time of receipt of the data unit to its delivery destination where data is accessible to customer. In terms of latency, two grades of delivery are provided by TMOD, subject to allocation of ground communication bandwidth to all competing missions:

(1) Grade-1 Delivery (Complete Delivery), through which mission data delivered are correct, in order, without omission and duplication, achieves a typical latency of $\leq$ 5 minutes.

(2) Grade-2 Delivery (Timely Delivery), through which mission data delivered are correct, in order, with potential omissions due to excessive transmission latency, and no duplication, achieves a typical latency in seconds. It will be used along with "off-line delivery" to retrieve omitted data. ("Off-line Delivery" is primarily used for data recall. It is also used for postpass delivery to those customers whose receiving system is not on-line during the pass. Typical latency will be hours.)

7.3 Spacecraft Time Correlation Services

The following metrics is applicable to the time services:

(1) Sampling interval

The project and mission requirements determine the resolution and stability of the spacecraft clock needed to adequately perform the mission. However, for time services, the spacecraft oscillator must be sufficiently stable that in the worst case no more than one tracking pass per 24 hours is required. TMOD will schedule the required tracking passes and make the required measurements.

(2) Accuracy

The accuracy of the correlation coefficients predicted or determined by TMOD is dependent on the following factors:

- Accuracy of station UTC clock and mechanism used to time tag the received telemetry
- Behavior of spacecraft clock due to measurable environmental changes
- Spacecraft data system and on-board network timing delays and errors
- Error in propagation delay (light time) in predicted or determined orbit
- Resolution of DSN timing equipment. Currently this is better than 1 micro second.
- Number of measurement samples.

Since these components are independent, the expected end-to-end accuracy is the standard deviation of the contributing factors. Typically, an accuracy of 100 microseconds may be achieved during the pass during which time calibration measurements are being made. Interpolated values between passes will have a lesser accuracy depending on the stability of the oscillator between measurement periods, but this can be improved by using the temperature history from the playback data in the modeling of the oscillator behavior.

The accuracy of predicted correlation coefficients is dependent on how far in advance of the measurements the prediction is made.

(3) Timeliness of delivery

Predicted correlation coefficients will be provided to the customer as requested. Validated correlation coefficients are provided to the customer within 2 hours but no later than 24 hours after the conclusion of the pass during which measurements were made. (This gives time to fix anomalies by using data from another time calibration pass.)

7.4 Tracking and Navigation Services

7.4.1 Raw Radio Metric Measurement Service

7.4.1.1 Doppler Data

Doppler data are the measure of the cumulative number of cycles of a spacecraft's carrier frequency received during a user specified count interval. The exact precision to which these measurements can be made is a function of received signal strength and station electronics, but is a small fraction of a cycle. Raw Doppler data is generated at the tracking station and delivered via DSN interface TRK-2-34, for 34m and 70m stations and in format TRK-2-30 for 26 m antennas. In order to acquire Doppler data, the user must provide a reference trajectory, and information concerning the spacecraft's RF system to TMOD to allow for the generation of pointing and frequency predictions.

The user specified count interval can vary from 0.1 sec to 10 minutes, with count times of 10 to 60 seconds being typical. The average rate-of-change of the cycle count over the count interval expresses a measurement of the average velocity of the spacecraft in the line between the antenna and the spacecraft. The accuracy of Doppler data is quoted in terms of how accurate this velocity measurement is over a 60 second count. The accuracy of data improves as the square root of the count interval.

(1) Noncoherent Doppler Data

Noncoherent data (also known as one-way data) is data received from a spacecraft where the downlink carrier frequency is not based on an uplink signal. The ability of the tracking station to measure the phase of the received signal is the same for non-coherent versus coherent data types, however the uncertainty in the value of the reference frequency used to generate the carrier is generally the dominant error source.

(2) Coherent Doppler Data

Coherent Doppler data is that received from a spacecraft where the reference frequency of the received carrier signal was based on a transmitted uplink signal from the Earth. This is commonly known as two-way data, when the receiving and transmitting ground stations are the same, and three-way data, when the transmitting and receiving stations are different. Since the frequency of the original source signal is known, this error source does not affect data accuracy. The accuracy of this data is a function primarily of the carrier frequency, but is affected by transmission media effects.

• S-band: S-band (2.2 GHz) data is available from 26m and 70m antennas. The accuracy of S-band data is approximately 1 mm/s for a 60 second count interval after being calibrated for transmission media effects. The dominant systematic error which can affect S-band tracking data is ionospheric transmission delays. When the spacecraft is located angularly close to the Sun, with Earth-spacecraft-Sun (EPS) angles of less than 10 degrees, degradation of the data accuracy will occur. S-band data is generally unusable for EPS angles less than 5 degrees.

- X-band: X-band (8.4 GHz) data is available from 34m and 70m antennas, although X-band transmission is not available from 70m antennas. X-band data provides substantially better accuracy than S-band. The accuracy of a 60 second X-band Doppler measurement is approximately 0.1 mm/s. X-band data is less sensitive to ionospheric media delays but more sensitive to weather effects. X-band data is subject to degradation at EPS angles of less than 5 degrees, but is still usable with accuracies of 1 to 5 mm/s at EPS angles of 1 degree or less.

7.4.1.2 Ranging Data

Ranging data measures the time that it takes a series of signals superimposed upon the uplink carrier frequency to reach the spacecraft, be retransmitted, and then received at an Earth station (round-trip-light-time, RTLT). As such, all DSN ranging systems are intrinsically coherent.

The user of ranging data service must define two of three required parameters: the desired accuracy, the desired range measurement ambiguity, and the maximum observation time. These along with the knowledge of the received ranging power-to-noise ratio will allow for the configuration of the ranging system.

(1) Sequential Ranging

The 26m, 34m, and 70m subnets utilize the DSN Sequential Ranging Assembly (SRA). For strong signals the SRA can provide measurements of the range to the spacecraft to 1 meter precision at X-band and to 2 meters precision at S-band. However, data accuracy is a function of signal strength and for ranging data via a spacecraft low gain antenna at typical deep space ranges, the data accuracy may be degraded to as much as 1 km.

The SRA modulates a series of codes upon the radio signal to the spacecraft. The first of these, the “clock code,” defines the resolution or accuracy that the ranging measurement will have. However, the observation from the clock code is ambiguous as it only identifies the fractional part of the clock code period comprising the RTLT, there are an unknown additional integer number of clock periods composing the RTLT. The SRA, then sequentially modulates a decreasing series of lower frequency codes upon the signal in order to resolve the ambiguity in the range measurement, by increasing the period of the ranging code. The maximum range ambiguity possible in the DSN ranging system is approximately 152,000 km, however ambiguities of 1,190 km and 2,380 km are more commonly used.

The accuracy of a ranging observation is a function of the received power-to-noise ratio in the ranging signal. Greater accuracy can be achieved by observing the “clock code” signal for a longer period of time. For lower power-to-noise ratios it also takes longer to resolve each of the ambiguity resolution codes. Consequently, for a given power-to-noise ratio, a desired accuracy and a desired ambiguity will result in a required observation time. For practical purposes the maximum value for this observation time is 30 minutes. In the event that the desired accuracy and desired ambiguity result in a required observation time greater than 30 minutes, either a change in the ambiguity or the accuracy will be required. DSN Document 810-5, Module TRK-30 provides a detailed description and the formula used in calculating the accuracies.

(2) 26m Ranging

In addition to the SRA, the 26m subnet also supports a second order ranging system which is a hybrid system combining a harmonic side tone ranging system with a binary encoded ambiguity resolving code. This system operates only at S-band and provides a measurement accuracy varying from 1 to 10 meters for Earth orbiting spacecraft. The ambiguity of the measurement is 644,000 km. If a user requests this data, the interface is via DSN interface TRK2-30.

7.4.1.3 Angle Data

The DSN 26m subnet has the capability to provide closed loop pointing to a spacecraft being tracked and to report the resulting azimuth and elevation of the antenna. This angle data which is primarily used to support low Earth orbiters and for launch support is accurate to approximately 0.02 degrees. Angle data does not require a coherent signal, but is only available at S-band. A customer wishing to receive raw angle data service would receive the data via DSN interface TRK-2-30.

7.4.2 Validated Radio Metric Data Service

Currently, the Validated Radio Metric Data Service introduces a delay of 30 minutes to 1 hour in delivery of data, however, upgrades, i.e. the Automated Radiometric Data Conditioning (ARDC), now being implemented will decrease this to less than two minutes.

7.4.3 Orbit Determination Service

7.4.3.1 Radio Metric Orbit Determination

The performance of the radio metric orbit determination is described in terms of an Earth-centered Earth Equatorial Radial-Transverse-Normal coordinate system. Accuracy is principally a function of the amount of tracking, Earth relative geometry, and data types utilized. The following captures the typical one sigma capability:

(1) Coherent Doppler only, spacecraft geocentric declination greater than 10 degrees --
- Range: 10 km
- Transverse & Normal: 250 meters for every 1,000,000 km from the Earth (e.g. 37.5 km at 150 million km geocentric range)

(2) Coherent Doppler only, spacecraft geocentric declination less than 10 degrees --
- Range: 10 km
- Transverse & Normal: 500 meters for every 1,000,000 km from the Earth (e.g. 75 km at 150 million km geocentric range)

(3) Coherent Doppler and Ranging, spacecraft geocentric declination greater than 10 degrees --
- Range: <1 km
- Transverse & Normal: 100 meters for every 1,000,000 km from the Earth (e.g. 15 km at 150 million km geocentric range)

(4) Coherent Doppler and Ranging, spacecraft geocentric declination less than 10 degrees --
- Range: <1 km
- Transverse & Normal: 150 meters for every 1,000,000 km from the Earth (e.g. 22.5 km at 150 million km geocentric range)

7.4.3.2 Automated Orbit Determination

The performance of the automated orbit determination is described in terms of an Earth-centered Earth Equatorial Radial-Transverse-Normal coordinate system. Accuracy is principally a function of the amount of tracking, Earth relative geometry, and data types utilized. The following captures the typical one sigma capability:

(1) Coherent Doppler only, spacecraft geocentric declination greater than 10 degrees --
- Range: 10 km
- Transverse & Normal: 350 meters for every 1,000,000 km from the Earth (e.g. 52.5 km at 150 million km geocentric range)

(2) Coherent Doppler only, spacecraft geocentric declination less than 10 degrees --
- Range: 10 km

- Transverse & Normal: 750 meters for every 1,000,000 km from the Earth (e.g. 112.5 km at 150 million km geocentric range)

(3) Coherent Doppler and Ranging, spacecraft geocentric declination greater than 10 degrees --
- Range: <1 km
- Transverse & Normal: 150 meters for every 1,000,000 km from the Earth (e.g. 22.5 km at 150 million km geocentric range)

(4) Coherent Doppler and Ranging, spacecraft geocentric declination less than 10 degrees --
- Range: <1 km
- Transverse & Normal: 225 meters for every 1,000,000 km from the Earth (e.g. 34 km at 150 million km geocentric range)

7.5 Radio Science Services

Key performance characteristics of radio science services in metrics such as frequency stability, phase noise, and amplitude stability, are described in Module RSS-10 of Document 810-5, Vol. 1 "DSN-Flight Project Interface Design Handbook".

7.6 VLBI Services

Key performance characteristics of VLBI services in terms of accuracy of VLBI measurements are described in Module VLBI-10 and VLBI-20 of Document 810-5, Vol. 1 "DSN-Flight Project Interface Design Handbook".

8. Description of Tool Delivery Process

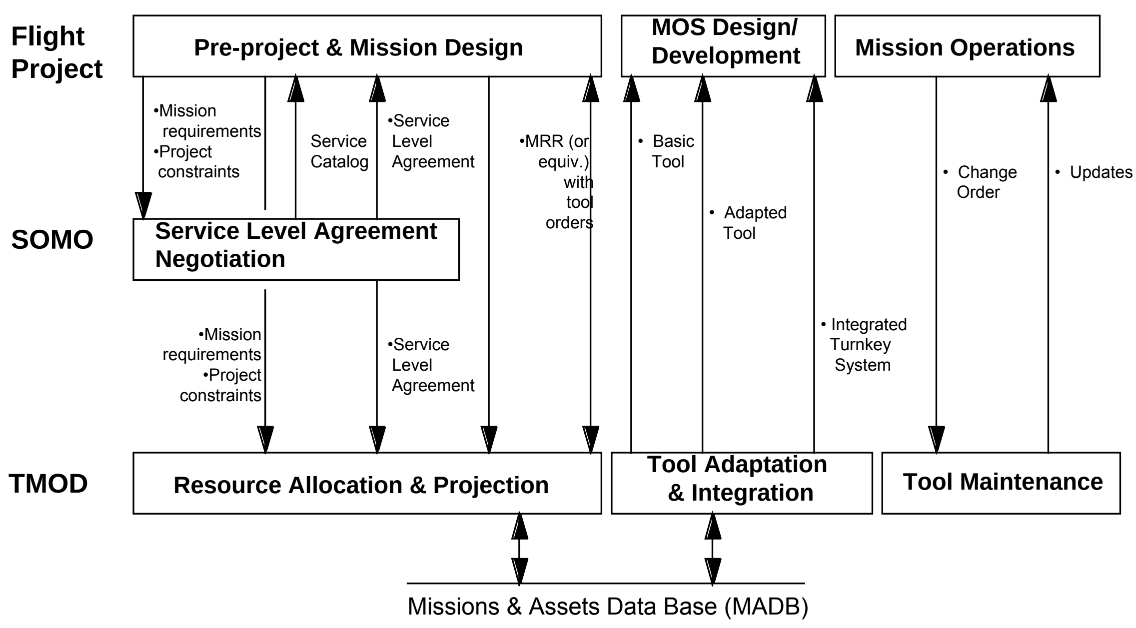
Most of the components involved in providing the services described in the Services Catalog can be supplied to the customer as a tool. These tools will be used by the customer to perform some or all of the services themselves.

Figure 8.1 shows the customer interface for tools. There are three options for tools:

(1) TMOD delivers a turnkey system to the customer to use to provide an integrated set of functions.
(2) TMOD supplies tools configured and tailored to meet the customer requirements. The customer is responsible for integrating the tool into their system.
(3) TMOD provides the tool as is, and the customer is responsible for customization and integration. This option is not available for all tools.

TMOD will provide maintenance of the tool over the life of the mission as negotiated. Different levels of maintenance are available.

Figure 8.1 Customer Interface for Tools: Process Over the Project Life Cycle



9. List of Tools and Functional Description of Tools

TMOD can provide an extensive set of mission operations tools to augment and extend a customer's existing systems (for example, the system used for mission integration and test) or commercial-off-the-shelf systems. Tools are provided for all aspects of mission applications, observation planning, scheduling/sequencing support, spacecraft modeling, simulation, state tracking, prediction, and performance analysis. These tools typically require adaptation, configuration or extension to meet a mission's unique requirements. TMOD tool providers can adapt the tools as part of the tool supply process to a mission. Alternatively, customers may choose to do the adaptation themselves.

For obtaining detailed information about specific tools, the customer is advised to contact TMOD personnel via the mechanism described in Sec.2. A Government-use license for temporary use of the following software tools may be obtainable through the JPL cognizant Government procurement officer.

9.1 Command Tools

The Command Tools provide for the command delivery function of mission operations.

9.1.1 Command Delivery Tools

The command tools provide the capability for user to encapsulate command loads into a set of command link transmission units (CLTU) and transmit them to the station for radiation according to the station interface protocol.

A command protocol handling tool which includes, in addition to the above capabilities, the feature of closing the command loop with the spacecraft using standard ARQ mechanisms such as CCSDS COP-1 or SCPS.

9.1.2 Automated Command Tracker

This tool set provides functions to manage and track command files and to automate the command review and approval process. It includes functions to support electronic review and approval of command loads using secure means for user authentication.

9.2 Telemetry Tools

Telemetry Toolset can be provided as a turnkey telemetry system dedicated to the acquisition, processing, storage, and delivery of data products to the user. Telemetry processing at any of the 4 different levels: frame, packet, channel data (i.e. telemetry measurement), and data set (i.e. file), can be selectively configured by the user.

9.3 Mission Analysis Tools

These tools provide an extensive set of spacecraft and telecommunications link analysis functions.

9.3.1 Telecommunications Analysis Tools

Telecommunications Analysis Tools generates link design control table showing the uplink and downlink telecommunications performance. It takes into account the configuration and characteristics of spacecraft telecommunication subsystem, the selected capabilities and configuration of DSN tracking stations, trajectory geometry, etc. for estimating future uplink and downlink signal strength, signal-to-noise ratios (SNR), best lock frequency, Doppler frequency offsets, etc. These predict tools may also assist customers in specifying the spacecraft telecommunication system parameters during the mission design phase.

9.3.2 Spacecraft Performance Analysis Tools

The Spacecraft Performance Analysis Tools support system-level analysis of spacecraft and science instrument performance and health. They are used to correlate the assessed behavior of power, thermal, guidance and dynamics, telecommunications, and other on-board conditions, from a spacecraft system perspective, against expected performance. These tools use the engineering data to perform trend analysis and other functions. Some of the tools maintain their own internal state tables describing the status of all relevant spacecraft elements. These tools typically have to be heavily adapted to a given spacecraft architecture, instrument, and communications configuration.

9.4 Mission Data Management Tools

Several different tools are provided to support the different aspects of data management in the mission data repository.

The data management tools provide interfaces to the various processing systems and to the mission control system. API's are provided to permit direct integration of the data management and catalog functions into other applications.

9.4.1 Data Management Tools

The tools include data catalog capabilities with several query and access interfaces, both GUI and command line versions are available to support direct user access or automation. Data may be queried and fetched on demand and subscription capabilities are provided that can be programmed to automatically deliver different classes of data as it arrives. The data storage functions provide both open access and managed access modes to provide data security and access control as required. Storage is extensible to accommodate short term or life of mission applications and in some case the storage and catalogs may be distributed for load balancing.

9.4.2 Data Products Tools

Tools to create a wide variety of data products are made available. Data products may include simple annotated copies of engineering and science data sets written to a variety of magnetic and optical media as well as production of a fully annotated set of data on write once or mastered CD-ROMs.

9.5 Experiment Product Tools

A suite of tools is provided to process image, spectral, radar, time series, and other data forms. These tools may be invoked via a user interface which provides command line, GUI, and on-screen visual programming supported by extensive on-line help. The entire suite of tools may be used in a highly interactive data exploratory mode or programmed for automated processing of large data volumes.

9.5.1 Science Data Processing Tools

These tools are used to produce "level 1A&B" products generated in non-real-time after the creation of the raw level zero data products. This processing may include merging of telemetry data received from multiple sources into the best available set of data, removal of instrument signature, mathematical transformation of time series data, and data quality checks. Higher level processing may include true color reconstruction from multiple exposures, cartographic projections and generation of large image mosaics.

9.5.2 Science Data Visualization Tools

These tools are used to convert the science data products into forms that can be displayed or printed for visual interpretation. This may include animation sequences, mathematical transformation of time series data, visualization products portraying data from multiple instruments, and visualization products of multispectral data. Other tools are available to perform "data mining" operations, scanning large volumes of data for particular signatures or artifacts.

9.5.3 Photo Product Tool

Photo products containing any level of processing may include enhancement applied to improve interpretability and annotation specified by the science team. Annotation can include engineering data, ancillary data (e.g. spacecraft attitude, instrument pointing, etc.), N-dimensional histograms, gray scales of color bars, etc.

9.5.4 Cartographic Tools

These are the tools which can be used to support precise cartographic projections, derive elevation maps from stereo/SAR imagery, Cartographic projections for bodies other than the Earth including irregular bodies.

9.6 Navigation Ancillary Data Tools

The Navigation Ancillary Data Tools permit creation of reduced and interpreted ancillary datasets which may include spacecraft ephemeris, planetary ephemeris and constants, instrument descriptions, camera pointing, events about spacecraft and instruments. The output from these tools may be used to annotate observations or otherwise record mission analyses, events and processing states. Packaged as an integrated toolset, the Navigation Ancillary Information Facility (NAIF) tools have been used by many flight projects and PIs in a variety of different science domains. While providing generalized capabilities, they have to be adapted for use by a particular mission.

9.7 Mission Control Tools

Mission control tools displays spacecraft engineering telemetry data for customers to monitor the health and safety of the spacecraft. It gives the capability to ingest, process, and display the data in real-time with a built-in automated alarm/alert mechanism. A spacecraft commanding tool gives the capability to generate commands. Also provided are tools to monitor the ground system performance.

9.8 Instrument Control Tools

Instrument control tools displays instrument telemetry data for customers to monitor the health and safety of the instrument. The tools permit monitoring the real-time and playback instrument engineering data and quick-look science data and near real-time evaluation of instrument health and safety status. The instrument commanding tool gives the capability to generate instrument commands.

9.9 Planning and Scheduling Tools

Planning and scheduling tools are used to plan overall mission scenarios and observation sequences, to create schedules for communication, spacecraft, and instrument activities, to create command sequences and translate them into a form suitable for transmission to the spacecraft. Planning tools include resource analysis, link and resource forecasting, and predicts generation. The planning process may also make use of spacecraft and instrument simulators, trajectory generators, viewperiod predictors, and ephemerides which are described separately.

9.9.1 Sequence Planning Tools

These tools provide sequence generation, validation, and review capabilities for standard mission commanding scenarios. The input to these tools are the mission and observation plans, current spacecraft state, allocations of tracking passes, and associated viewperiod, lighttime, and other predicts. Output of these tools are validated command sequences suitable for uplink to the spacecraft, an integrated schedule of spacecraft and ground data system events, and other information used to predict and validate spacecraft operation.

9.10 Test and Simulation Tools

Test and simulation tools are available to support testing and evaluation of the system and its components. These include test data simulators, GDS testbed, and spacecraft state or subsystem simulators.

9.10.1 Data Simulation Test Tool

Data simulators are a toolset provided to generate simulated RF signals, spacecraft telemetry frames and packets, science data frames, and other data artifacts. Data streams may be clean or have a variety of different typical noise signatures, data gaps, or other anomalous artifacts inserted. These tools can be used to generate data streams that include typical framing, encoding, and compression schemes that are in use, permitting easy creation of realistic test data sets or streams. Many of these are standard tools which are readily adapted to new mission data profiles.

9.10.2 Spacecraft Simulation Test Tool

These test tools provide a rudimentary simulation of the spacecraft to support ground system development and test. The test tool generates telemetry data and accepts commands. It implements the command protocol and provides command verification through command counters. The content of the telemetry parameters can be scripted to provide a variety of data patterns. Selected errors and anomalies can also be scripted.

The test tool typically generates spacecraft and instrument housekeeping data at real time data rates. Science data can be included as canned data, but this is limited to moderate data rates (typically less than 100 kbps).

9.10.3 GDS Test Tool

TMOD provides a GDS test tool to support the flight system development and test. It is available in two different forms. First, the Test Telemetry and Command Subsystem (TTACS) Core allows data to flow to and from the spacecraft without the operational ground/spacecraft interfaces. It provides serial telemetry and command interfaces between the spacecraft GSE and specially configured TMOD command and telemetry software resident at the various workstations. The TTACS Core includes the following

(1) a high-speed serial device for the interface with spacecraft GSE,
(2) the Test Telemetry Interface (TTI) software that receives and processes the telemetry data from the test spacecraft hardware and transmit it to the other GDS components in the testbed environment
(3) the Test Command Interface (TCI) software that processes command files from the GDS components into blocks of command bits and delivers them to the test spacecraft hardware.

The second form of the GDS test tool is the Test Telemetry and Command Subsystem (TTACS), which is essentially a miniature version of the entire GDS with a configuration needed to support the development and test of the spacecraft and MOS. Varying from project to project, it can be configured to include, in addition to the TTACS Core, certain number of parallel telemetry streams, finite number of data rates, a few workstations, data management capabilities, GSE interface, instrument BCE connections, etc. A final configuration of the TTACS is used to support the pre-launch system tests.

9.11 Integrated Ground Data System

TMOD supplies integrated ground data system (GDS) as a turnkey system for the customer to operate their mission. The GDS includes computer platforms and a complete suite of tools described above in this section. Adaptation of any part of the GDS for mission specific needs can be provided by TMOD. On-going maintenance of the GDS during the project life cycle will also be available.

9.12 Instrument Development Tools

These are the tools used for instrument development in the following areas:

- Ground Support Equipment - Tools to support Instrument Ground Support Equipment (IGSE) and its environment
- Flight Software Development - Tools and development environment to support instrument Software development
- Instrument modelling - Mathematical models of remote sensing instruments
- Calibration/Decalibration - Tools to support the calibration analysis for science instruments
- Data Compression/decompression - Tools to support the selection and development of science data compression algorithms including simulation

of an end-to-end data system covering the path from photon to final science product

10. Engineering Support Activities and Description of Each Activity

TMOD engineering personnel will be available to support customers in conducting pre-project studies, mission design, development of data systems, and/or the operations of missions. In general, these are level-of-effort support activities. The scope of each engineering support activity will have to be assessed on a case-by-case basis.

10.1 Systems Engineering

TMOD can provide systems engineering support to missions to assist them in defining a end-to-end telecommunications and mission operations system architecture, defining operations concepts, identifying system solutions, and defining interfaces.

10.2 Advance Mission Planning

TMOD provides a team of mission designers to work with potential customers who are exploring mission designs and concepts, preparing mission proposals, or developing early mission studies for possible new starts. The team serves as the earliest point of contact for identifying and coordinating TMOD customer needs and requirements.

Additionally, TMOD provides a team of navigation experts to work with potential customers to explore tracking and navigation concepts in support of proposal preparation and mission design. Tradeoffs such as; radiometric vs. optical tracking, on-board navigation vs. ground support, and a variety of guidance, navigation and control options are among the design characteristics considered. It is important to identify TMOD customer tracking and navigation needs early in the study phase since they can have a significant impact on spacecraft and mission design attributes.

10.3 Trajectory and Orbit Design

Trajectory and orbit design is available to assist the customer in establishing the interplanetary trajectory or orbit parameters most applicable to the objectives and requirements of a given mission or mission phase. This includes the process of determining and specifying an achievable orbit or trajectory for a spacecraft, to meet predetermined conditions.

10.4 GDS/MOS Management

TMOD can assist a customer in managing the ground data system development and operations. TMOD can provide assistance in planning the development, test and operations of the mission, identifying risks and recommend mitigating strategies, evaluating the design and operational readiness of the end-to-end data system and operations. TMOD data system management expertise can also be available to help define the project transitions from launch to nominal operations to the extended mission phase.

10.5 End-To-End Integration and Test

During spacecraft development phase, TMOD provides simulation and test capabilities in telecommunications to customers without the presence of the actual user spacecraft. TMOD also supports customer's test of end-to-end telecommunications link and characterization of spacecraft telecommunications subsystem during flight operations.

Mission operations services provided by TMOD will be available during development phase to support mission specific end-to-end integration and tests involving flight instruments (in engineering model or simulator), spacecraft (in engineering model, simulator, or flight system testbed), and project MOS.

10.6 RF Compatibility Test

Before launch, RF compatibility test equipment will be available for customer to validate the RF interface compatibility between the spacecraft and TMOD tracking network. The compatibility test equipment emulates the data modulation/demodulation capabilities and provides an RF link between the user spacecraft and tracking network.

10.7 Telecommunications Design

The telecommunications design can be conducted during mission design phase to help a customer achieve a flight segment telecommunications design which is compatible with the space-ground link and capabilities of DSN tracking stations, and will achieve the desired level of performance. Design issues, potential deficiencies and possible trade-offs are identified through these analyses. In general, the support is dependent on project phases:

(a) Phase A (Preliminary Design): Initial telecommunications link design includes trial selection of transponder or transceiver, power amplifier, antenna type, data rate determination, and channel coding schemes. The purpose is to assess feasibility and derive initial cost estimates. Also, basic tracking support issues are identified, e.g. required DSN capabilities, tracking schedule, navigation data types, and mission unique features.

(b) Phase B (Detailed Design): Detailed design includes final selection of spacecraft telecommunications components, transponders, power amplifier, antenna patterns, trajectory geometry, function cross strapping, and redundancy management. Link losses based on spacecraft dimensions and coax or waveguide selections are included with ground antenna G/T curves, spacecraft pointing models, Doppler and Doppler rates, for all link functions, i.e. telemetry, command, ranging, and radio science if present.

(c) Phase C/D (Implementation, Integration, and Test): All of the design work of Phase B is maintained with measurements of actual flight hardware performance. Performance estimates are adjusted by changes in values from their earlier estimates, as well as by reductions in uncertainties allowed by measured versus estimated values. Discrepancies are analyzed for their effects and corrective actions. Mission operations adaptations are completed, sequences are built for testing on the spacecraft and for use in flight. Compatibility with the DSN is proven by test, and end-to-end tests from mission operations system to spacecraft.

10.8 Spectrum and Frequency Management

TMOD has the responsibility of assisting SOMO in managing NASA's spectrum and frequency resources. In that capacity, TMOD helps the customer license the use of the RF spectrum, performs conflict analysis, make frequency allocation and interference avoidance/mitigation recommendation, and handles the licensing process with other government agencies.

10.9 System Administration

TMOD system administrators install and configure mission-related workstations, routers, and firewalls. This may include MOS software, third-party, and World Wide Web (WWW) installation. Mission-related LAN troubleshooting is also available.

10.10 Security Engineering

The TMOD Security Engineer arranges all interconnections between the (closed) Flight Operations Network and the (open) Internet. The primary path is through the TMOD Firewall. Technology may include one-time passwords issued by a "Smart Card." Security engineering support may be provided to the requesting Flight Project. This includes preliminary design and cost estimates for end-to-end network security.

11. Pricing of Services and Tools

As NASA moves to a full cost accounting model, it is important that the pro-rata share of each service's cost be determined and budgeted by each mission. This section provides some pricing information intended to assist in estimating part of the MOS costs. Since the TMOD Services Catalog is a planning tool for potential and actual customers, it is our policy that the pricing information is accurate enough for flight projects to estimate costs for TMOD services in the conceptual design and planning phases of the mission. However, refinement of cost estimates may be made by working with TMOD personnel as a mission progresses down to implementation phase. Actual commitments are made through the SOMO Service Level Agreement (SLA) process. The TMOD Telecommunications and Mission Service (TMS) Managers are available to customers for establishing TMOD commitments.

11.1 Pricing of Services by Individual Service Types

Table 11.1 lists the prices of individual service types are included. Total service costs are the sum of both pre-launch development and post-launch operations prices for all service types subscribed by a mission and depend upon the duration of the services required. Customers must first identify the specific types of services they need. They also need to determine the number of years, and fractions thereof, that these services will be required during the operational phase. Labor costs are stated in *Work-Months* to insulate data from inflation factors. For FY'98, a burdened *Work-Month* is about $13K. Hardware costs and other fees are all in FY'98 dollars and will have to be adjusted in order to be applicable to a different year.

Table 11.1 TMOD Service Fees

Service Type	Pre-Launch Pricing		Post-Launch Pricing		Note
	Work Force (Work Months)	**Hardware** (FY'98 $)	**Work Force** (Work Months)	**Fees** (FY'98 $)	
1. Command	9.0/mission	$20K	0.5/mo	Aperture fee + $100/uplink hour	1
2. Telemetry	12/mission	$40K	1.0/mo	Aperture fee + $40/downlink hour	1
3. Mission Data Management	16/mission + (3.0/mission)	$40K + $2K/10GB	(0.2 mission/ mo)		2, 3
• Short term data retention			0.5/mo	Aperture fee + $7K/mo	1
• Long term data repository	1.0/instrument		0.1/mission/ mo		4
• Archive product preparation	4.0/instrument		0.2/instrument / mo		4
4. Tracking & Navigation	Ref. to Pricing Algorithm		Ref. to Pricing Algorithm	Aperture fee	1, 5
5. Experiment Data Products					
• Level 1 processing ("standard" instrument)	8.0/instrument	$25K	0.2/mission/ mo	N/A	
• Level 1 processing (multispectral, etc.)	minimum 14/instrument	$25K	0.3/mission/ mo	N/A	
• Higher-level Processing	Minimum 6.0/instrument	$50K	0.4/instrument /mo	N/A	
• Photo products	2.0/instrument	$2.5K	0.1/mission/ mo	media costs	
• Sense of Active Presence - virtual reality based on telemetry, science data, models, etc.	minimum 4.0/instrument	From $10K to ???	0.1/instrument /mo	N/A	
• Data visualization and animation incorporating navigation, ephemeris, CAD, and remotely sensed data/imagery	minimum 2.0/mission visualization	$5K	0.1/instrument /mo	N/A	
• Science Visualization	2.0/mission visualization	$5K	1.0/mission/ mo	N/A	
6. Flight Engineering					
• Spacecraft health/safety monitoring	10/mission	$50K	0.6/mo	N/A	
• Spacecraft performance analysis	Call for Info	Call for Info	Call for Info	Call for Info	
• Telecomm link analysis	29/mission	$50K	0.6/mo	N/A	
• Spacecraft time correlation	5.0/mission	$25K	0.1/mo	N/A	
• Instrument health/safety monitoring	15/instrument	$50K	0.4/instrument /mo	N/A	
7. Sequence Engineering	Call for Info	Call for Info	Call for Info	Call for Info	
8. Science Observation Planning					
• In situ science/instrument observation	10/instrument	$15K	1.0/instrument /mo	N/A	
• Remote sensing science/ instrument observation	2.0/instrument	$15K	0.4/instrument /mo	N/A	

Table 11.1 TMOD Service Fees (Continued)

Service Type	Pre-Launch Pricing		Post-Launch Pricing		Note
	Work Force (Work Months)	**Hardware** (FY'98 $)	**Work Force** (Work Months)	**Fees** (FY'98 $)	
9. Ground Communications & Information					
• Ground network					
- Data communications	N/A	N/A	N/A	$13K/year	6
- Voice communications	N/A	N/A	N/A	$24K/year	7
- Video communications	N/A	N/A	N/A	Free	
• Data transport	N/A	N/A	N/A	Free	
• Collaborative					
- Distributed File System (DFS or AFS)	N/A	N/A	N/A	$0.3K/year/ user account	
- Distributed Computing Environment (DCE)	N/A	N/A	N/A	Call for Info	
- Collaborative Environment	N/A	N/A	N/A	Call for Info	
10. Radio Science	N/A	N/A	N/A	Aperture fee	1
11. VLBI	N/A	N/A	N/A	Aperture fee	1
12. Radio Astronomy	N/A	N/A	N/A	Aperture fee	1
13. Radar Science	N/A	N/A	N/A	Aperture fee	1

Notes on Table 11.1:

1. Reference to Aperture Fee – Hourly Rates for DSN Antenna Utilization. Aperture fee is applied to service pricing, based on the hourly rate of antenna utilization, regardless of the types of services subscribed by a mission. In other words, the hourly rate is charged regardless whether a mission subscribes to only a single service, e.g. telemetry service, or a few services, e.g. telemetry, command, and tracking services.
2. These price items are considered baseline charges for mission data management services, regardless whether a mission subscribes to only a single service type or all the three.
3. The pre-launch development workforce of 16 work months include 12 work months for non-science data and 4 work months for science data, i.e. that is processed to level 1 or above. The price items in parenthesis are applicable for the low latency data distribution of science data.
4. These are additional price items applicable to the data management of science data.
5. For pricing the navigation services, i.e. orbit determination, trajectory analysis, and maneuver planning services, refer to the Pricing Algorithm for Navigation Services. The price for radiometric data services is included in the aperture fee.
6. This is a typical price based on 128 kbps data rate sharing a ground T1 line between JPL and the location of an end user. The price reflects a fraction of the total T1 circuit cost.
7. This is a typical price based on 5 voice circuits of total 24 circuits sharing a T1 line for voice communications between JPL and the location of an end user.

11.2 Aperture Fee – Hourly Rates for DSN Antenna Utilization

The algorithm for computing DSN *Aperture Fees* embodies incentives to maximize DSN utilization efficiency. It employs *weighted hours* to determine the cost of DSN support. The following equation can be used to calculate the *hourly Aperture Fee* (AF) for DSN support.

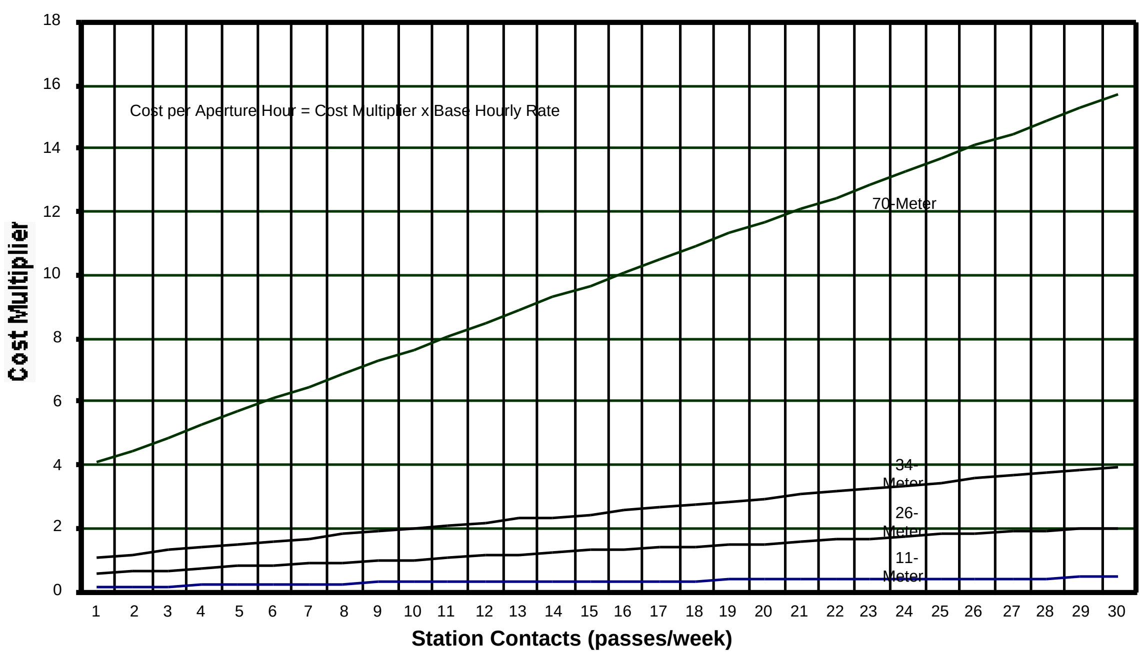
$$AF = R_B [A_W (0.9 + F_C / 10)]$$

where:

- AF = weighted *Aperture Fee* per hour of use.
- R_B = base hourly rate = \$560.00/hr in FY98 dollars).
- A_W = aperture weighting:
  - = 0.1 for 11-meter stations (stations have <u>very</u> limited capability).
  - = 0.5 for 26-meter stations.
  - = 1.0 for 34-meter stations.
  - = 4.0 for 70-meter stations.
- F_C = number of station contacts, (contacts per calendar week).

The *weighting factor* graph below shows relative antenna costs. A *station contact* may be any length but is defined as the lesser of the spacecraft's viewperiod or 12 hours. Total DSN cost is obtained by partitioning mission into calendar weeks and summing the *Aperture Fees*. This total cost can be

WEIGHTED DSN STATION COSTS



obtained by grouping weeks having the same requirement, multiplying by *Aperture Fee*, and summing over the mission's duration.

11.3 Pricing Algorithm for Navigation Services

An estimate for the price of navigation services can be obtained from:

$$\boldsymbol{P} = \sum_{p=1}^{P} \kappa_p C_p \Delta t_p + \sum_{e=1}^{E} \kappa_e C_e + \sum_{s=1}^{S} \kappa_s C_s \Delta t_s$$

where

$\boldsymbol{P}$ = price in FY99 $ (for FY'98 $ adjust by 3.1%)

P = number of mission *phases* considered *(see definition below)*

E = number of planned *events (see definition below)*

S = number of mission *spans (see definition below)*

p,e,s = indicies for mission *phases, events, and spans* respectively

C_p = cost for knowledge and technology base in $ month (see Table 11.3-1)

Δt_p = duration of each mission *phase* in months

C_e = cost for each *event* in $ (see Table 11.3-2)

C_s = cost incurred during a *span* in $ per month (see Table 11.3-3)

Δt_s = duration of each *span* months

$\kappa_{p,e,s}$ = complexity/inheritance factor (see Table 11.3-4)

- *<u>Phases</u> are defined by the standard mission phases A, B, C/D, and E.*
- *<u>Events</u> are characterized by intense activities that last for a few days to weeks, usually no more than 2 months.*
- *<u>Spans</u> are characterized by low level activities that typically last more than a few months.*

Table 11.3-1: Knowledge and Technology Base

Description	C_p
Phase A&B	$ 10K/mo
Phase C/D	$ 15K/mo
Phase E	$ 10K/mo

Table 11.3-2: Events

Event Description	C_e
Launch (includes post-launch checkout & 1st TCM)	$ 90K
Trajectory Correction Maneuvers (TCMs) during cruise	$ 10K/each
Target Body Encounter/Flyby: Planetary	$ 90K/each
Target Body Encounter/Flyby: Small Body	$ 60K/each
Target Body Orbit Insertion Maneuver	$ 30K
Target Body Orbit Trim Maneuvers (OTMs)	$ 10K/each
Atmosphere Entry & Landing, including Earth	$ 50K
Planetary Assent	$ 100K
Small Body Rendezvous & Landing	$ 50K/each
Spacecraft Rendezvous & Docking	$100K/each

Table 11.3-3: Mission Spans

Mission span description	C_s

Ballistic Cruise to Target Body, including Earth	$ 10K/mo
Target Body Orbiter	$ 20K/mo
Aerobraking	$ 75K/mo
Natural Satellite Tour	$100K/mo

Table 11.3-4: Complexity/Inheritance Factors

Description	$K_{p,e,s}$
Uses existing capabilities or procedures, particularly autonomy	0.5
Requires minor enhancement to existing capabilities or procedures	1.0
Requires extensive enhancement to existing capabilities or procedures	1.5
Requires entirely new capabilities or procedures	3.0*

* Assumes the needed technology has been developed and is readily available for infusion into operational environment of the DSMS.

Figures in the above 4 index tables are subject to periodic refinement through parameter tuning and changes in the number of missions subscribing to the navigation services.

11.4 Pricing of Services for MOS Cost Estimate - A Sample

It is important to point out here that the total MOS cost for a given mission cannot be assessed solely based on its ground system design. In fact, the MOS cost is very much dependent on the complexity of the mission, which is a function of the mission and science objectives, the operability of the spacecraft, and the mission operations policy. To illustrate the cost of TMOD services (Ref. to Table 11.4) derived for a typical Discovery class mission, we include a sample fact sheet depicting the characteristics of the mission profile and the spacecraft for a fictitious mission X. The fact that the total service cost is roughly 50% of the total MOS cost of Mission X should also give one an idea about the dependency of the MOS cost on mission complexity and spacecraft operability.

Sample Fact Sheet Used for MOS Cost Estimation – Mission X

Mission Characteristics

- Launch in mid '04
- Mission duration is approximately four years
- Mission design includes an EGA flyby, an asteroid flyby, and a comet rendezvous with approximately eighteen-months of operations near the comet
- Maximum range to the spacecraft will be about 5 A.U., Comet rendezvous occurs near 2.2 A.U.
- Except for the asteriod flyby, no cruise science is planned

Spacecraft Characteristics

- The spacecraft design provides large margins, significant redundancy, and 90% of the spacecraft is based on flight-proven hardware
- On board software provides fault detection and recovery. On board software will track and report summarized engineering information regarding spacecraft health, safety, and trends. These reports will be downlinked weekly
- The spacecraft will utilize SEP technology, and the spacecraft will thrust continuously until a comet rendezvous trajectory is achieved
- The high gain antenna is body-fixed. Two omni antennas are provided. The link design will support a 1.5 kbps data rate at the maximum range (5 A.U.) with 3 dB margin into a 34-meter DSN BWG antenna. The spacecraft operates at X-band for all communications
- The spacecraft is three-axis stabilized
- The spacecraft includes three science instruments and one engineering instrument that will also provide science data. Radio science will be conducted using the radio system. Included are 2, 8 and 50 degree FOV cameras, and a radar system
- Two Gbits of memory are available on-board for data storage

Other Key Considerations

- The Project intends to minimize MOS development and operations costs by adapting and reusing existing capabilities and utilizing multi mission services
- Tracking support will be limited to that necessary to assure the spacecraft's health and safety

Mission Phase	Tracking Coverage (34-Meter Antenna)
Launch	Continuous Tracking for 30 Days
Cruise Periods	One Four-hour Track per Week for 118 Weeks
Asteriod Flyby	One Ten-hour Track per Day for 10 Days
Earth-Gravity Assist	One Ten-hour Track per Day for 10 Days
Comet Approach	One Ten-hour Track per Day for 30 Days
Orbit Insertion	Continuous Tracking for 10 Days
Orbital Operations (Decent Events)	Continuous Tracking for 24 Hours, Ten Events
Orbital Operations (Routine)	One Ten-hour Track per Day (Five-Days per Week) for 78 Weeks

and to accomplish mission objectives. Weekly contacts are planned during cruise, but the Project will tolerate a gap of up to two weeks without contact before pursuing supplementary tracking. The Table provides tracking coverage plans.

- The Project will not plan to staff outside of normal working hours, peak activity periods will be supported through use of overtime and increased reliance on multi mission services
- Autonomous-optical navigation will be utilized for cruise navigation. Optical and radio metric navigation will be used for near comet operations with the comet-descent sequence executed autonomuously and under control of a descent radar system

- Mission-tailored tools will be developed to support science planning and spacecraft sequence development
- Science processing will by done by the PI and Co-I's, JPL will provide a data repository of files received from the spacecraft for downloading to the primary science data collection site at the PI's home institution

Table 11.4 Sample TMOD Service Costs – Mission X

		Pre Launch			Post Launch		
TMOD Services, Tools, & Engineering Support	**Required Functionality**	**Labor (WM)**	**H/W ($K)**	**Total ($K)**	**Fee ($/Period)**	**Total ($K)**	**Total Cost for Service (FY98 $K**
1. Command	Command Radiation	9	20	137	100	0	137
2. Telemetry	Frame through Data Set	6	40	118	40	0	118
3. Mission Data Managemen	Short Term Data Retention	10	100	230	7000	0	230
4. Experiment Data Products	Level 0 Processing for Visual and IR p OpNav Support	17		231		106	337
5. Tracking & Navigation	All Except Maneuver Planning	47	63	674		600	1274
6. Flight Engineering							
• Telecom Analysis	Performance Analysis	15	10	205	68000	0	205
• Mission Control	R/T Coordination & Configuration Control	10	100	230	160000	0	230
• S/C Time Correlation	Clock Calibration Files	1.3		17	1300	0	17
7. Sequence Engineering	Uplink Process Control	54		700		200	900
8. Ground Communications	All Functions	1	100	113	55000	0	113
9. Mission Planning Tools	Mission/Science Planning, Adaptation Observation Planning Tools	24		312	6000	0	312
10. Engineering Support	All Functions (includes System Admin)	46	6	604	199000	112	716
11. Telemetry End User Too	All Functions	10		130	43000	0	130
		250.3	439	3701		1018	4719
PHASE C/D COSTS				**3701**			
PHASE E COSTS						**1018**	

12. Acronyms and Abbreviations

AMMOS	Advanced Multi-Mission Operations System
API	Application Program Interface
ARDC	Automated Radiometric Data Conditioning
ARQ	Automatic Retransmission Request
BCE	Bench Checkout Equipment
BWG	Beam Waveguide
CCSDS	Consultative Committee for Space Data Systems
CDE	Consolidated Development Environment
CLTU	Command Link Transmission Units
CMSM	Center Mission Service Manager
COP	Command Operations Procedure
CSR	Customer Support Rooms
DADM	Data Acquisition, Delivery, and Management
DFS	Distributed File System
DN	Data Numbers
DSCC	Deep Space Communications Complexes
DSMS	Deep Space Mission System
DSN	Deep Space Network
EPS	Earth-Spacecraft-Sun
ERT	Earth Receive Time
EU	Engineering Units
FTS	Frequency and Timing Subsystem
GDS	Ground Data Systems
GPS	Global Position System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GUI	Graphic User Interface
HEF	High Efficiency
ICC	Integrated Computer Complex
ICT	Integer Cosine Transform
IGSE	Instrument Ground Support Equipment
JPEG	Joint Photographic Engineering Group
MADB	Missions & Assets Data Base
MOS	Mission Operations System
MSM	Mission Service Manager
NAIF	Navigation Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NISN	NASA Integrated Service Network
NSSDC	NASA Space Science Data Center
OD	Orbit Determination
ODRC	Operations Data Reduction Complex
PCD	Project Commitment Document
PDS	Planetary Data System

POCC	Payload Operations Control Center
PSLA	Project Service Level Agreement
QQCL	Quality, Quantity, Continuity and Latency
RF	Radio Frequency
RMDC	Radio Metric Data Conditioning Service
RSS	Radio Science Services
RTLT	Round-Trip-Light-Time
SCPS	Space Communications Protocols Standard
SLA	Service Level Agreement
SLE	Space Link Extension
SNR	Signal-to-Noise Ratio
SOMO	Space Operations Management Office
SPICE	Spacecraft Planetary Instrument Camera Event
SRA	Sequential Ranging Assembly
TDM	Time Division Multiplexed
TDRS	Tracking and Data Relay Satellites
TMO	Telecommunications & Mission Operations
TMOD	Telecommunications & Mission Operations Directorate
TMS	Telecommunications & Mission Services Manager
TTACS	Test Telemetry & Command Subsystem
UTC	Coordinated Universal Time
VCDU	Virtual Channel Data Units
VLBI	Very Long Baseline Interferometry

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